Fecal Bacteria and General Standard Total Maximum Daily Load Development for Knox Creek and Pawpaw Creek

Prepared for
Virginia Department of Environmental Quality
April 26, 2006

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ACKNOWLEDGEMENTS

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VADEQ, Southwest Regional Office

Virginia Department of Conservation and Recreation (VADCR)

Virginia Department of Forestry, Abingdon Regional Office (VADOF)

Big Sandy Soil and Water Conservation District (BSSWCD)

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Local citizens and stakeholders in the Knox Creek and Pawpaw Creek watersheds

MapTech, Inc. of Blacksburg, Virginia, supported this study as a subcontractor to
New River-Highlands RC&D,
through funding provided by
Virginia Department of Environmental Quality contract #99

EXECUTIVE SUMMARY

Background and Applicable Standards

Knox Creek

According to the *1996 303(d) TMDL Priority List* (VADEQ, 1997), Knox Creek (waterbody ID # VAS-Q03R) was listed as impaired. The 18-mile impaired segment represents the main stem of Knox Creek from its headwaters to the Kentucky state line; the stream runs through Hurley and Kelsa in Buchanan County, VA. The biological monitoring station at 6AKOX011.08 showed that aquatic life is partially supporting.

On the *1998 303(d) Total Maximum Daily Load Priority List and Report*, Knox Creek was listed for General Standard (benthic) impairment. The Knox Creek segment was recalculated as 16.94 miles in the *2002 303(d) Report on Impaired Waters*. In addition to the General Standard (benthic) violation, this report lists Knox Creek for fecal coliform and fish tissue – PCBs. A Total Maximum Daily Load (TMDL) for PCBs will be addressed at a later date.

On the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report*, Knox Creek was listed for General Standard (benthic), total fecal coliform, and fish tissue - PCBs. A benthic survey previously completed rated the stream as moderately impaired.

Pawpaw Creek

Pawpaw Creek (waterbody ID # VAS-Q03R) is located along Route 643 north of Grundy in Buchanan County; the impaired segment includes the entire 4.52-mile length of Pawpaw Creek from the Kentucky state line to the confluence with Knox Creek. Pawpaw Creek was first listed as impaired in 1994. It appeared again on the *1996 303(d) TMDL Priority List* for violations of the General Standard (benthic) based on monitoring at VADEQ biological station 6APPW000.60.

According to the *1998 303(d) Total Maximum Daily Load Priority List and Report*, Pawpaw Creek was identified as not supporting aquatic life uses based on the modified

Rapid Bioassessment Protocol II (RBPII) at station 6APPW000.60; it was rated as severely impaired.

Pawpaw Creek remained on the *2002 303(d) Report on Impaired Waters* and the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* for violations of the General Standard (benthic). It continued to be rated as severely impaired.

TMDL Endpoint and Water Quality Assessment

Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source (NPS) contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, urban/residential runoff, failed and malfunctioning septic systems, and uncontrolled discharges (straight pipes). There are currently seven active non-mining permitted point sources associated with the Knox Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Two are single-family wastewater permits. These discharges are small (<1,000 g/day) and are expected to meet the 126-cfu/100 mL *E. coli* standard. Two are discharges from local schools, which are permitted for fecal control. One is a construction stormwater discharge permit not permitted for fecal coliform discharge.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* target was a geometric mean not exceeding 126-cfu/100 mL and a single sample maximum of 235-cfu/100 mL. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

General Standard (benthic)

A TMDL must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but generally do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (USEPA, 2000a) was used to identify stressors affecting Knox Creek and Pawpaw Creek. Chemical and physical monitoring data from VADEQ monitoring stations provided evidence to support or eliminate potential stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter.

The results of the stressor analysis are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

The results indicate that total dissolved solids (TDS) is the Most Probable Stressor for Knox Creek and was used to develop the benthic TMDL. The results indicate that sediment and TDS are the Most Probable Stressors for Pawpaw Creek and were used to develop the benthic TMDLs.

Sources contributing to the TDS impairment include both nonpoint contributions and point sources. Nonpoint sources in the Knox Creek watershed are abandoned mine land (AML) (*e.g.,* mine spoils, benches, and disturbed areas), urban areas, and land currently being mined.

Sediment is delivered to Pawpaw Creek through surface runoff, streambank erosion, and natural erosive processes. During runoff events, sediment is transported to streams from land areas. Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Land disturbances from mining, forest harvesting, and construction accelerate erosion at varying degrees. Sediment transport is a natural and continual process that is often accelerated by human activity. Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater, and construction stormwater discharge.

Modeling Procedures

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology, TDS loads, and fecal coliform loads.

For purposes of modeling the Knox Creek watershed inputs to streamflow and in-stream fecal bacteria, the drainage area was divided into twenty-four subwatersheds. Four subwatersheds (20-23) make up the Pawpaw Creek watershed, which flows into Knox Creek.

A paired watershed approach was utilized to calibrate the hydrology of Knox Creek. The Upper Powell River was used as a paired watershed. Further hydrologic calibration was performed using data from the Department of Mines Minerals and Energy in-stream monitoring point identification stations (MPIDs). A stable time period used for hydrologic calibration covered the period 10/1/1994 through 9/30/1997. Hydrology validation was not performed for Knox Creek or Pawpaw Creek because a stable time period was chosen for hydrology modeling and all observed data collected during this time period was used for hydrology calibration. It was determined that using all available data for calibration would result in a more accurate model.

Fecal Coliform

The fecal coliform calibration for Knox Creek was conducted using monitored data collected at VADEQ monitoring station 6AKOX006.52. Modeled fecal coliform levels matched observed levels indicating that the model was well calibrated.

The allocation precipitation time periods were selected as the years with the most representative rainfall compared to all historic data. The time period used for allocation was 10/1/1996 through 9/30/1999.

General Standard (benthic) – TDS

There are no existing in-stream criteria for TDS in Virginia; therefore, a reference watershed approach was used to define allowable TDS TMDL loading rates in the Knox Creek watershed and the Pawpaw Creek watershed. Dismal Creek in Buchanan County, VA was selected as the reference watershed for Knox Creek due to its similar size, shape and location, as well as similar soils, and slope. The value used as the endpoint for the TDS TMDL was 369 mg/L. Middle Creek in Tazewell County, VA was selected as the TMDL reference for Pawpaw Creek due to its history of mining activity and recovery from a benthic impairment. The value used as the endpoint for the TDS TMDL was 334 mg/L.

General Standard (benthic) - Sediment

To define allowable sediment TMDL loading rates in the Pawpaw Creek watershed the reference watershed approach was used. Middle Creek in Tazewell County, VA was selected as the TMDL reference for Pawpaw Creek due to its history of mining activity and recovery from a benthic impairment. The TMDL sediment loads were defined as the modeled sediment load for existing conditions from the non-impaired Middle Creek watershed, and area-adjusted to the Pawpaw Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling between both the impaired creek and reference creek.

Existing Conditions

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock in the Knox Creek watershed are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock. Contributions from all of these sources were updated to 2005 conditions to establish existing conditions for the watershed. The HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the Knox Creek watershed.

General Standard (benthic) - TDS

Both point and nonpoint sources of TDS were represented in the model during the hydrology and TDS calibration periods. Permitted sources included discharges of runoff through control structures (sediment retention ponds), as well as discharges from deep mines. Deep mine discharges were modeled by adding a time series of pollutant and flow inputs to the stream. Nonpoint sources were modeled as having three potential delivery pathways, delivery with TDS in surface runoff, delivery through interflow, and delivery through groundwater.

General Standard (benthic) - Sediment

The sediment TMDL goal for Pawpaw Creek was defined by the average annual sediment load in metric tons per year (t/yr) from the area-adjusted Middle Creek. The existing conditions and future conditions were calculated for Pawpaw Creek.

The sediment TMDL is composed of three components: waste load allocations (WLA) from permitted point sources, the load allocation (LA) from nonpoint/non-permitted sources, and a margin of safety (MOS), which was set to 10% for this study. The target sediment TMDL load was 5,430 t/yr. The current load from Pawpaw Creek is 10,287 t/yr.

Load Allocation Scenarios

Fecal Coliform

The next step in the bacteria TMDL process was to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard and 0% exceedance of the single sample maximum *E. coli* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. The final TMDL information is shown in Table E.1.

The following is the recommended load allocation scenario for Knox Creek:

- 87% reductions in direct wildlife loads,
- 94% reductions in NPS wildlife loads
- 89% reductions in direct livestock loads,
- 99.5% reductions in NPS loads from agricultural and urban/residential areas, and
- 100% reductions in loads from straight pipes.

Table ES.1 Average annual *E. coli* loads (cfu/year) modeled after allocation in the Knox Creek watershed at the outlet.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Knox Creek	4.53E+10	1.74E+13	Implicit	1.75E+13
VA0026972	*1.39E+10*			
VA0067521	*2.96E+10*			
VAG400180	*8.71E+08*			
VAG400391	*8.71E+08*			

Correcting all straight pipes, reducing nonpoint agriculture and urban/residential loads by 98%, and reducing direct livestock loads by 89% results in a 9.51% violation of the instantaneous standard and is the Stage 1 implementation goal.

General Standard (benthic) – TDS

The next step in the Knox Creek TDS TMDL process was to adjust TDS loadings from existing watershed conditions to reduce the various source loads to levels that would result in an in-stream TDS concentration less than 369 mg/L. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed along the impairment of Knox Creek (subs 1-7).

Table ES.2 Average annual TDS loads (kg/yr) modeled after TMDL allocation in the Knox Creek impairment.

Allocation	Description	TDS (kg/year)
Waste Load Allocation[1]		**1.11E+06**
Permit Number:	MPID	
1401358	*6070139*	
1200159/1201641	*1431*	
VA0026972		
VA0067521		
VAG400180		
VAG400391		
Transient Loads[2]		
1100279	*5880524,5880526 - 5880528,5880531 - 5880535*	
1100321	*6080573*	
1101400	*6070142 - 6070158*	
1101550	*2024 - 2031*	
1200034	*6082883, 6082884*	
1200038	*6082893 - 6082896*	
1200101/1201637	*6083006*	
1200158/1201646	*6083112*	
1200202	*6083177*	
1200840	*6084226 - 6084228*	
1201085	*6084523*	
1201238	*6070095*	
1201275	*5670260*	
1201303/1201706	*6070116*	
1201501/1201708	*1359*	
1201527/1201709	*1744*	
1300114/1301728	*6084597*	
1300160/1301657	*6084617, 6084618*	
1300191/1301644	*6084627, 6084628*	
1300229/1301714	*6084657 - 6084663*	
1300236	*6084668*	
1300261/1301712	*6084682, 6084683*	
1300558	*6085096, 6085097*	
1300236/1301723/1301727	*6070104, 6070105*	
1400190	*6085543*	
1401242	*6070098 - 3070101*	
1401255	*6070106 - 6070108*	
1401312	*1768, 5670329 - 5670331*	
1401358	*6070132 - 6070139*	
1401570/1401734/1601089	*6086035, 6086036*	
Load Allocation		**6.85E+06**
TMDL		**7.97E+06**

[1] TDS from WLA is presented as a combined load from all permitted sources.
[2] The waste load from runoff-controlling BMPs (*i.e.,* ponds) that are likely to be removed upon completion of current mining operations.

The next step in the Pawpaw Creek TDS TMDL process was to adjust TDS loadings from existing watershed conditions to reduce the various source loads to levels that would result in an in-stream TDS concentration less than 334 mg/L. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed along the impairment of Pawpaw Creek (subwatersheds 20 and 21).

Table ES.3 Average annual TDS loads (kg/yr) modeled after TMDL allocation in the Pawpaw Creek impairment.

Allocation		Description	TDS (kg/year)
Waste Load Allocation[1]			**1.52E+05**
Transient Loads[2]			
Permit Number:		MPID	
	1100572	*6081252,6081253*	
	1101530	*1758 - 1760*	
	1200025	*6082875*	
	1200036/1201729	*5670028*	
	1200619	*6083817*	
	1200619/1201715	*6083816*	
	1201070/1201733	*6084487, 6084488*	
	1201404	*6070165*	
Load Allocation			**2.56E+06**
TMDL			**2.71E+06**

[1] TDS from WLA is presented as a combined load from all permitted sources.
[2] The waste load from runoff-controlling BMPs (*i.e.,* ponds) that are likely to be removed upon completion of current mining operations.

No TDS reductions from permitted sources are currently quantified. If reductions from permitted sources are required in the future, the reductions will be made through the application of appropriate BMPs.

General Standard (benthic) - Sediment

The next step in the Pawpaw Creek sediment TMDL process was to reduce the various source loads to result in average annual sediment loads less than the target sediment TMDL load. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed at the outlet of Pawpaw Creek.

The final load allocation scenario for Pawpaw Creek recommends reductions to sediment loads from abandoned mine land (59%), disturbed forest (58%), and high tillage cropland (57%), and a 13% reduction to streambank erosion. Sediment loads from straight pipes need to be reduced 100% due to health implications and the requirements of the fecal bacteria TMDL. No reductions to sediment or TSS permitted sources were required.

Table ES.4 TMDL targets for the impaired watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS (t/yr)	TMDL (t/yr)
Pawpaw Creek	4.99	5,425	603.4	6,034

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the impairments on Knox Creek and Pawpaw Creek. The second step is to develop a TMDL implementation plan (IP). The final step is to implement the TMDL IP and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency (EPA) regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, to address the bacteria TMDL, reducing the human bacteria loading from straight pipes and failing septic systems should be a primary implementation focus because of the health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair program. Livestock exclusion from streams has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion.

It is anticipated that disturbed forest and AML will be the initial targets of implementation. Erosion and sediment deposition from disturbed land generally abate over time as new growth emerges. One practice that has been successful on some sites involves diversion ditches to direct water away from the disturbed area. Because logging is a common practice in the watershed, every effort must be made to ensure that the proper forest harvesting BMPs are used on future harvests.

To address the TDS and sediment TMDLs, it is anticipated that AML reclamation and the correction of straight pipes will be initial targets of implementation. One way to accelerate reclamation of AML is through remining. The Virginia Department of Mines, Minerals and Energy's (DMME) Division of Mined Land Reclamation (DMLR), The Nature Conservancy, Virginia Tech/Powell River Project, and U. S. Office of Surface Mining are in the process of developing incentives that will promote economically and environmentally beneficial remining operations that reclaim AML sites (DMME, 2004).

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list. The primary purpose of the TMDL is restoration of the aquatic community and not attainment of TDS/TSS waste load allocations. Should the benthic community recover prior to reaching TDS and TSS target loads, VADEQ and DMME will propose to EPA and the State Water Control Board (SWCB) that these waste load allocations be amended to reflect new information.

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Public Participation

During development of the TMDL for Knox Creek and Pawpaw Creek, public involvement was encouraged through two public meetings and one Technical Advisory Committee (TAC) meeting. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Knox Creek and Pawpaw Creek TMDLs were presented at the first of the public meetings. Details of the pollutant sources and stressor identification were also presented at this meeting. Public understanding of, and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period after the final public meeting and 4 written comments were received. Watershed stakeholders will have the opportunity to participate in the development of the TMDL IP.

PART I: BACKGROUND AND APPLICABLE STANDARDS

1. INTRODUCTION

1.1 Background

Total Maximum Daily Loads (TMDLs) are slated for the Knox Creek and Pawpaw Creek watersheds due to provisions of the Clean Water Act. The United States Environmental Protection Agency's (EPA) document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991), states:

> *According to Section 303(d) of the Clean Water Act and the USEPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The majority of the Knox Creek and Pawpaw Creek watersheds (contained in USGS Hydrologic Unit Code 05070201) are located in Buchanan County, Virginia with a small portion in Pike County, KY. Pawpaw Creek flows into Knox Creek near Kelsa, VA. This watershed is a part of the Tennessee/Big Sandy River basin, which drain via the Mississippi River to the Gulf of Mexico (Figure 1.1).

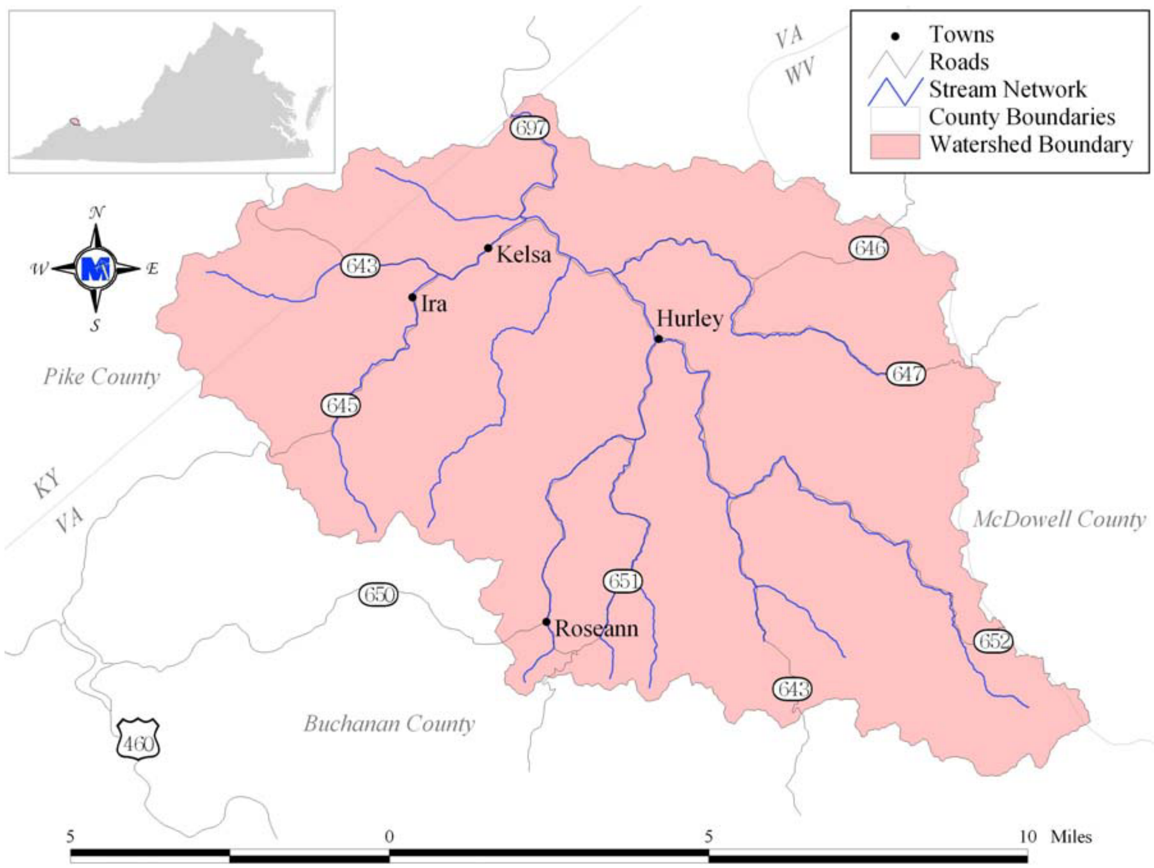

Figure 1.1 Location of the Knox Creek and Pawpaw Creek watersheds.

1.2 Tug Fork River

The EPA developed benthic TMDLs on the Tug Fork River in 2002 (EPA, 2002). The Tug Fork watershed (HUC 05070201) is located in the Big Sandy River basin, along the borders of Virginia, West Virginia, and Kentucky. Portions of the Virginia counties of Buchanan and Tazewell are within the Tug Fork River watershed area; Knox Creek and Pawpaw Creek are tributaries to Tug Fork River.

Table 1.1 shows the baseline and allocated loads for aluminum, iron, and manganese along with the margin of safety for the subwatershed that contains Knox and Pawpaw Creeks.

Table 1.1 Aluminum, iron, and manganese baseline and allocated loads.[1]

	Baseline Load (lb/yr)		Allocated Load (lb/yr)		MOS (lb/yr)	% Reduction
	NPS	PS	LA	WLA		
Aluminum	125,686	3,790	92,494	3,790	4,814	26
Iron	170,406	3,791	128,476	3,791	6,613	24
Manganese	--	--	--	--	--	--

Because the Tug Fork main stem was not listed for manganese impairment, no allocation is made for regions that only contribute to the Tug Fork mainstem.
[1]Data taken from: EPA. 2002. Metals and pH TMDLs for the Tug Fork River Watershed, West Virginia. U.S. Environmental Protection Agency Region 3. Philadelphia, PA.

It is anticipated that the implementation of BMPs to address the benthic TMDLs in this report will also decrease the aluminum, iron and manganese loads from Knox and Pawpaw Creeks thereby benefiting the Tug Fork River aquatic resources.

1.3 Knox Creek

According to the *1996 303(d) TMDL Priority List* (VADEQ, 1997), Knox Creek (waterbody ID # VAS-Q03R) was listed as impaired. The 18-mile impaired segment represents the main stem of Knox Creek from its headwaters to the Kentucky state line; the stream runs through Hurley in Buchanan County, VA (Figure 1.2). The Virginia Department of Environmental Quality (VADEQ) identified this segment as impaired with regard to the General Standard (benthic). The biological monitoring station at 6AKOX011.08 showed that aquatic life is partially supporting.

On the *1998 303(d) Total Maximum Daily Load Priority List and Report*, Knox Creek was once again listed for General Standard (benthic) impairment. The regional biologist commented on the sub-optimal habitat, noting that the banks were denuded and, thus, not stable.

The Knox Creek segment was recalculated as 16.94 miles in the *2002 303(d) Report on Impaired Waters*. In addition to the General Standard (benthic) violation, this report lists Knox Creek for fecal coliform and fish tissue – PCBs. Fecal coliform violations in three of 21 samples at station 6AKOX008.11 resulted in the listing. A TMDL for PCBs will be addressed at a later date.

On the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report*, Knox Creek was listed for General Standard (benthic), total fecal coliform, and fish tissue - PCBs. A benthic survey previously completed rated the stream as moderately impaired. During the 2004 assessment period, 12 of 27 samples taken at the ambient water quality monitoring station 6AKOX008.11 violated the fecal coliform standard, and three of nine samples taken at 6AKOX014.17 violated the standard.

1.4 Pawpaw Creek

Pawpaw Creek (waterbody ID # VAS-Q03R) is located along Route 643 north of Grundy in Buchanan County; the impaired segment includes the entire 4.52-mile length of Pawpaw Creek from the Kentucky State line to the confluence with Knox Creek (Figure 1.2). Pawpaw Creek was first listed as impaired in 1994. It appeared again on the *1996 303(d) TMDL Priority List* for violations of the General Standard (benthic) based on monitoring at VADEQ biological station 6APPW000.60. The stream was determined to be non-supporting of aquatic life at this station.

According to the *1998 303(d) Total Maximum Daily Load Priority List and Report*, Pawpaw Creek was identified as not supporting aquatic life uses based on the modified RBPII protocol at station 6APPW000.60; it was rated as severely impaired overall.

Pawpaw Creek remained on the *2002 303(d) Report on Impaired Waters* and the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* for violations of the General Standard (benthic). It continued to be rated as severely impaired overall. The reports note that there are many NPDES dischargers from coal mining in the watershed; these are believed to be the source for habitat degradation.

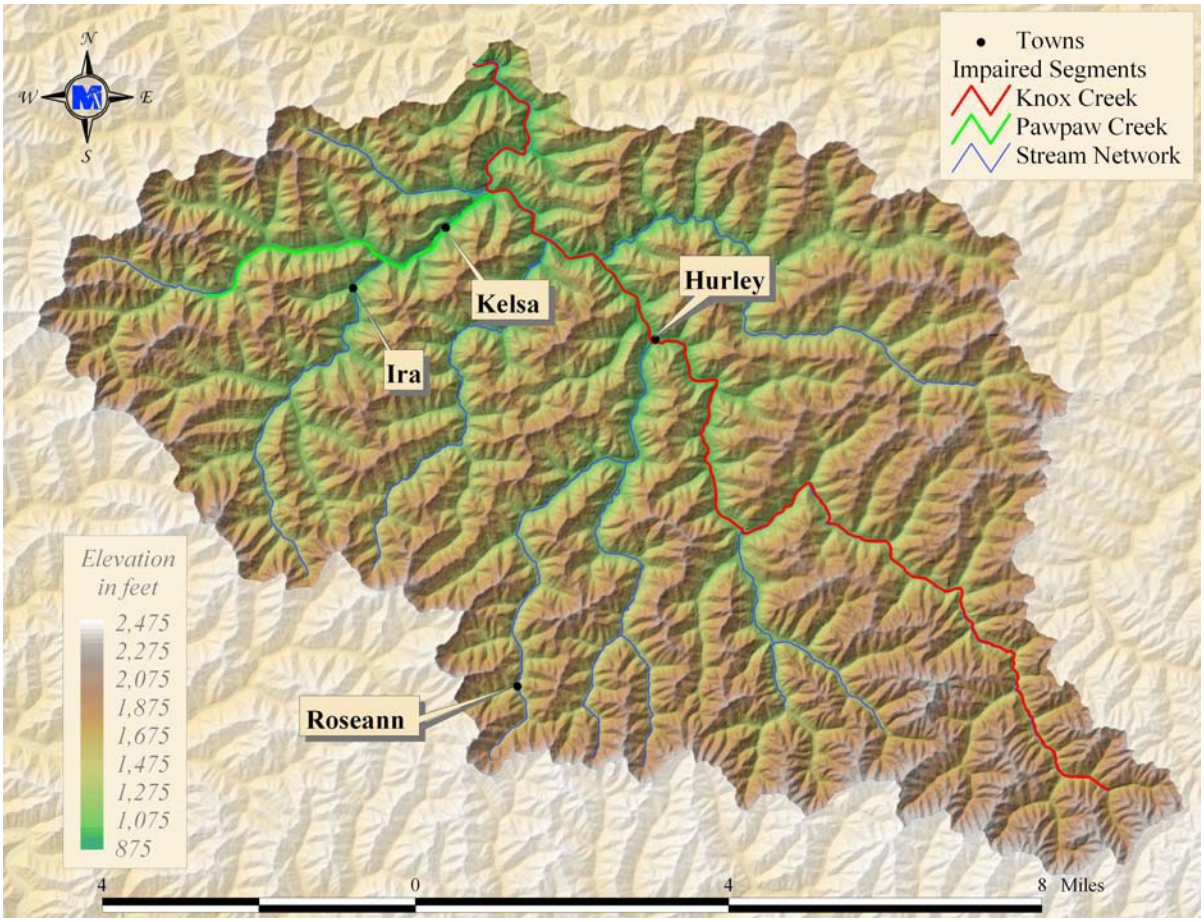

Figure 1.2 The impaired segments of Knox Creek and Pawpaw Creek.

PART II: FECAL BACTERIA TMDL

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to section 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means, "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses):

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Because this study addresses both fecal bacteria (Knox Creek) and benthic impairments (Knox and Pawpaw Creeks), two water quality criteria are applicable. Section 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC 25-260-20) applies to the benthic impairment.

2.2 Applicable Criteria for Fecal Bacteria Impairments

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a*

> *30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time.*

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The Environmental Protection Agency (EPA) has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard is in effect in Virginia as of January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows:

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

2. E. coli and enterococci bacteria per 100 mL of water shall not exceed the following:

	Geometric Mean[1]	*Single Sample Maximum[2]*
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDLs included in this study.

2.3 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Knox Creek fecal bacteria TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (section 2.1). In order to remove a waterbody from a state’s list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 mL and the instantaneous standard of 235 cfu/100 mL. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 mL and a single sample not exceeding 235 cfu/100 mL.

2.4 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Knox Creek is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Knox Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context, also include nonpoint sources that are not precipitation driven (*e.g.,* direct fecal deposition to stream).

A graphical analysis of measured fecal coliform concentrations versus the level of flow at the time of measurement showed that there is no critical flow level at VADEQ Station 6AKOX006.52 (Figure 2.1). Violations of the fecal coliform standards occur at all flow regimes at the station; there is no obvious dominance of either non-point sources or point sources. The graph of fecal coliform versus flow at VADEQ Station 6AKOX014.17 (Figure 2.2) shows two out of 11 samples violate the standard during low flows. The violations occurred during dry conditions at this section of Knox Creek; however, there is not enough information (samples taken) to determine if this is the only critical condition. Therefore, the fecal bacteria TMDL was developed to account for all flow regimes in Knox Creek.

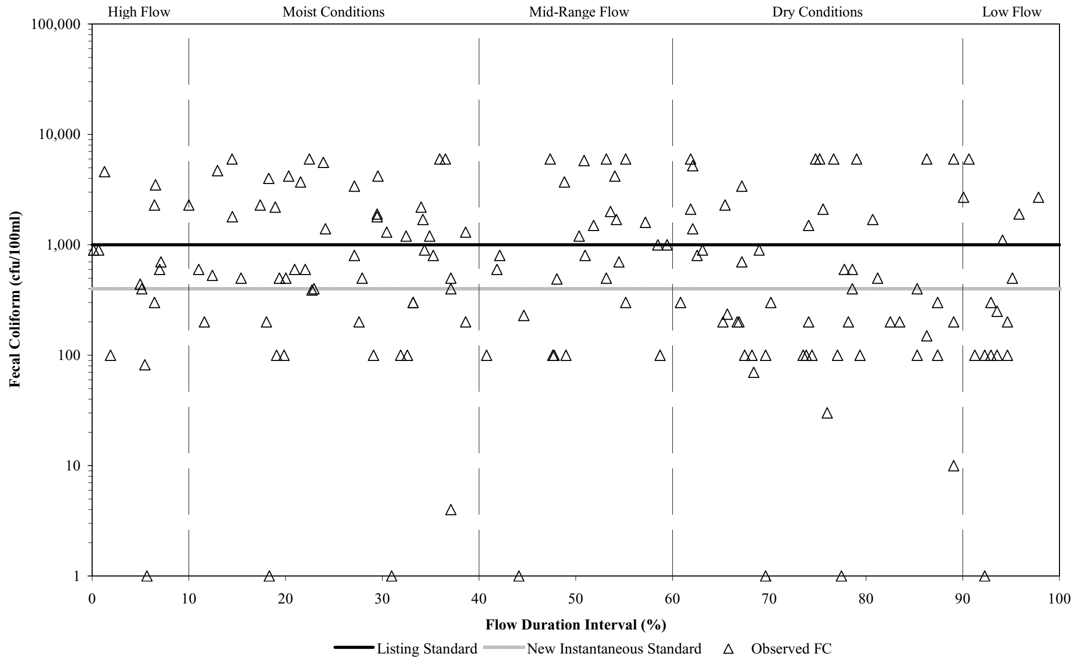

Figure 2.1 **Relationship between fecal coliform concentrations in Knox Creek (VADEQ Station 6AKOX006.52) and discharge at USGS Station #03207800.**

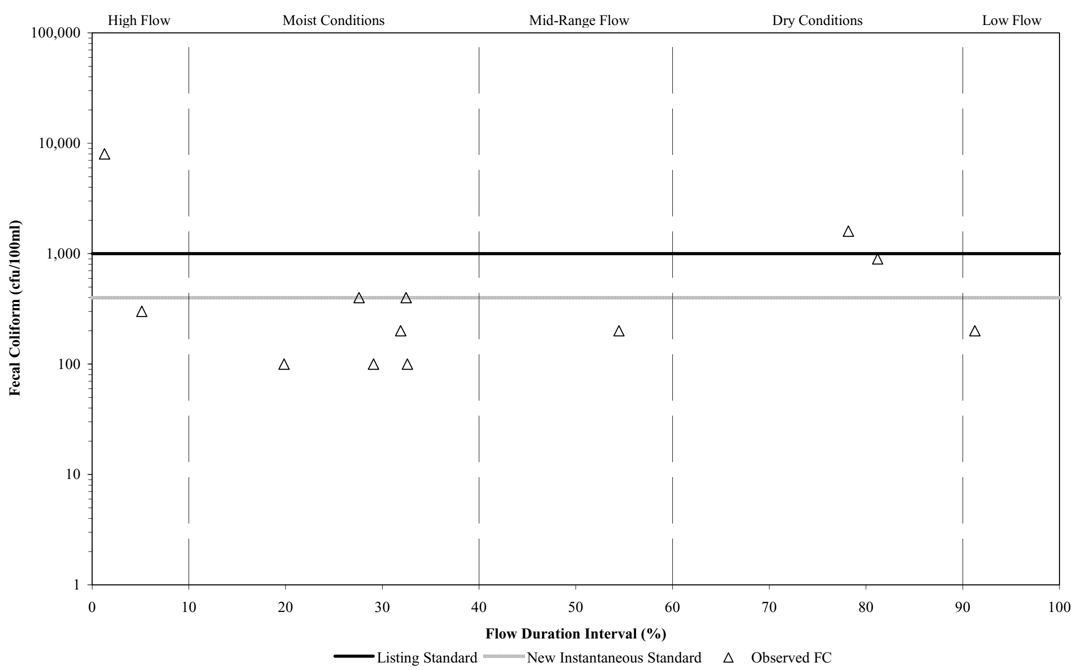

Figure 2.2 **Relationship between fecal coliform concentrations in Knox Creek (VADEQ Station 6AKOX014.17) and discharge at USGS Station #03207800.**

2.5 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream monitoring data throughout the Knox Creek watershed. An examination of data from water quality stations used in the Section 303(d) assessments and data collected during TMDL development was performed. Sources of data and pertinent results are discussed.

2.5.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information for Knox Creek are:

- bacteria enumerations from 3 VADEQ in-stream monitoring stations used for TMDL assessment (Figure 2.3, Tables 2.1 and 2.2), and
- bacterial source tracking from one VADEQ in-stream monitoring station analyzed during TMDL development.

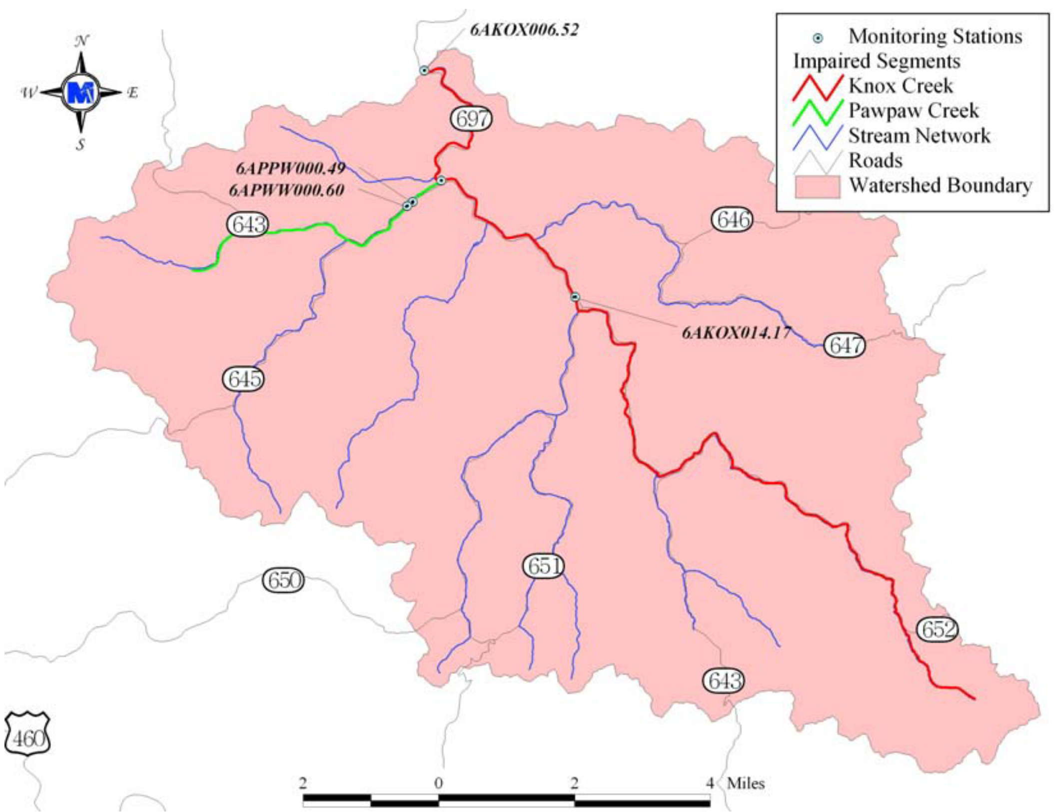

Figure 2.3 Location of VADEQ water quality monitoring stations in the Knox Creek watershed.

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for Knox Creek from February 1980 through June 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %	Violations[2] %
Knox Creek	6AKOX006.52	168	0	6,000	1,421	500	1,877	35	57
Knox Creek	6AKOX014.17	12	100	8,000	1,042	250	2,234	17	25

[1] Violations are based on the pre-2003 fecal coliform instantaneous standard (1,000 cfu/100mL)
[2] Violations are based on the current fecal coliform instantaneous standard (400 cfu/100mL)

Table 2.2 Summary of *E. coli* monitoring conducted by VADEQ for Knox Creek from November 2003 through June 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %
Knox Creek	6AKOX006.52	8	10	2,500	684	315	935	63

[1] Violations are based on the new *E. coli* instantaneous standard (235 cfu/100mL)

2.5.1.1 Water Quality Monitoring for TMDL Assessment

Data from in-stream bacteria samples in Knox Creek collected and analyzed by VADEQ from February 1980 through June 2004 (Tables 2.1 and 2.2) are included in this study. These tables summarize the bacteria samples collected at the in-stream monitoring stations used for TMDL assessment. Fecal coliform samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 1,000 cfu/100 mL. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or 16,000 cfu/100 mL most likely represent concentrations in excess of these values. *E. coli* samples were collected to evaluate compliance with the state's current bacterial standard, as well as for bacterial source tracking analysis. The current instantaneous standard for *E. coli* is 235 cfu/100mL.

2.5.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from July 2003 through June 2004 for Knox Creek. Specifically, water quality samples were taken at one site in the Knox Creek watershed station 6AKOX008.11 (Figure 2.4). All samples were analyzed for *E. coli* concentrations and for bacteria source (*i.e.,* human, livestock, pets, or wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech, Inc. Table 2.3 summarizes the *E. coli* concentration data at the ambient station. Bacterial source tracking (BST) is discussed in greater detail in section 2.6.1.

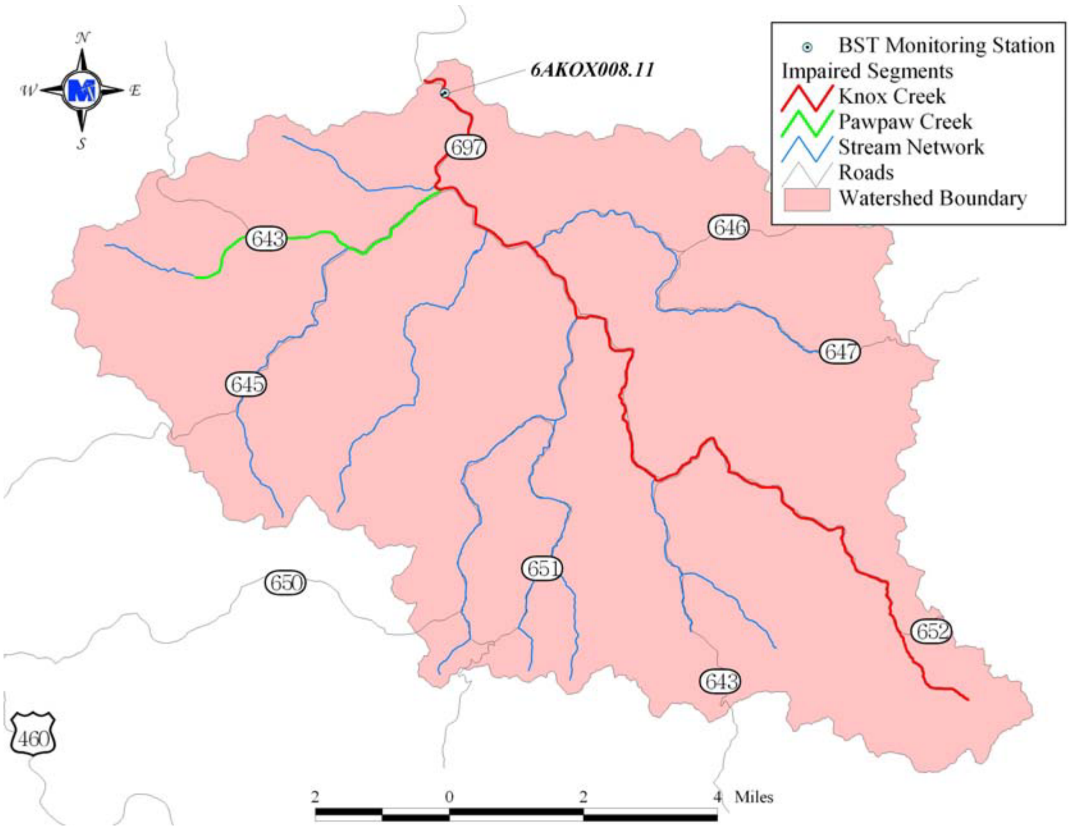

Figure 2.4 Location of the BST water quality monitoring station in the Knox Creek watershed.

2.6 Analysis of BST Data

2.6.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (*i.e.,* human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and improves the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The BST results were reported as the percentage of isolates acquired from the sample identified as originating from humans, pets, livestock, or wildlife.

BST results of water samples collected at an ambient station in the Knox Creek watershed are reported in Table 2.3. The BST results indicate the presence of all sources (*i.e.,* human, wildlife, livestock, and pets) contributing to the fecal bacteria violations. The fecal coliform and *E. coli* enumerations are given to indicate the bacteria concentration at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.,* **BOLD** numbers indicate a statistically significant result), determined through two tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (*alpha* = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations.

Table 2.4 summarizes the results with load-weighted average proportions of bacteria originating from the four source categories. The load-weighted average considers the level of flow in the stream at the time of sampling, the concentration of *E. coli* measured, and the number of bacterial isolates analyzed in the BST analysis. For Knox Creek, the predominate source of fecal bacteria was human, followed by wildlife, and pets. Livestock, while present, was the least persistent source. These results are consistent with local residents insight as to the sources of fecal contamination in the stream.

Table 2.3 Bacterial source tracking results from water samples collected in the Knox Creek impairment (6AKOX008.11).

Station	Date	*E. coli* (cfu/100 ml)	Percent Isolates classified as[1]:			
			Wildlife	Human	Livestock	Pets
6AKOX008.11	7/14/03	310	0%	4%	**42%**	**54%**
	8/11/03	700	0%	8%	**80%**	**12%**
	9/16/03	580	0%	8%	**88%**	4%
	10/14/03	140	7%	**27%**	13%	**53%**
	11/19/03	1800	**38%**	**41%**	4%	**17%**
	12/8/03	124	4%	**59%**	**12%**	**25%**
	1/6/04	280	4%	**29%**	8%	**59%**
	2/18/04	10	12%	12%	25%	51%
	3/15/04	10	0%	83%	17%	0%
	4/26/04	2500	8%	**33%**	**26%**	**33%**
	5/11/04	350	8%	**63%**	0%	**29%**
	6/22/04	500	**38%**	**42%**	8%	**12%**

[1]**BOLD** type indicates a statistically significant value.

Table 2.4 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Stream	Wildlife	Human	Livestock	Pet
6AKOX008.11	Knox Creek	28%	38%	11%	23%

2.6.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation and fecal coliform concentrations was conducted using the Mood's Median Test (MINITAB, 1995). This test was used to compare median values of precipitation, and fecal coliform concentrations in each month.

2.6.2.1 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The Seasonal Kendall Test was conducted on fecal coliform concentrations collected at stations used in TMDL assessment if sufficient data were available. Data at station 6AKOX006.52 showed a positive trend of 4.37. All stations in the Knox Creek watershed showed no seasonality in fecal coliform concentrations.

2.6.2.2 Precipitation

Daily precipitation measured at the Hurley 4S National Climatic Data Center (NCDC) Coop station #444190 in Hurley, Virginia and at the Grundy NCDC Coop station #443640 in Grundy, Virginia was used in analyses for Knox Creek. Total monthly precipitation measured in Grundy, Virginia was analyzed, and no overall, long-term trend was found. Total monthly precipitation measured in Hurley, Virginia was analyzed and an overall 0.014 trend was found.

A seasonal analysis of precipitation was conducted using the Mood's Median Test. This test was used to compare median values of precipitation in each month. Differences in mean monthly precipitation at Grundy are indicated in Table 2.5. Precipitation values in months with the same median group letter are not significantly different from each other at a 95% significance level. For example, January, February, March, April, May, June, July, August, and September are all in median group "B" and are not significantly different from each other. In general, precipitation in the spring-summer months tends to be higher than precipitation in the fall months.

Table 2.5 Summary of Mood's Median Test on monthly precipitation at Grundy, Virginia in the Knox Creek watershed.

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups[1]	
January	0.1286	0.036	0.389	A	B
February	0.1305	0.032	0.313	A	B
March	0.1366	0.043	0.362	A	B
April	0.1462	0.019	0.403	A	B
May	0.1619	0.041	0.298	A	B
June	0.1674	0.022	0.33	A	B
July	0.1664	0.044	0.286		B
August	0.1298	0.044	0.24	A	B
September	0.1219	0.036	0.223	A	B
October	0.1046	0.011	0.215	A	
November	0.1104	0.02	0.249	A	
December	0.1187	0.045	0.297	A	

[1]Precipitation in months with the same median group letter is not significantly different from each other at the 95% level of significance.

2.6.2.3 Summary of In-stream Water Quality Monitoring Data

A wide range of fecal coliform concentrations has been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Knox Creek watershed. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and non-point sections. The representation of the following sources in the model is discussed in section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between USGS and the EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources (when available) including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc-second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for each impaired watershed are given in Table 3.1.

Table 3.1 Contributing land use area.

Land use / Land cover	Acreage
Agricultural	**604**
Cropland	*432*
Livestock Access	*16*
Pasture / Hay	*156*
Forest	**53,491**
Abandoned Mine Land	*2,123*
Forest	*50,939*
Reclaimed Mine Land	*429*
Urban / Industrial	**1,403**
Active Mining	*1,158*
Residential	*54*
Salted Roads	*191*
Water	**625**

The land area of the Knox Creek watershed is approximately 56,123 acres, with forest as the primary land use (Figure 3.1).

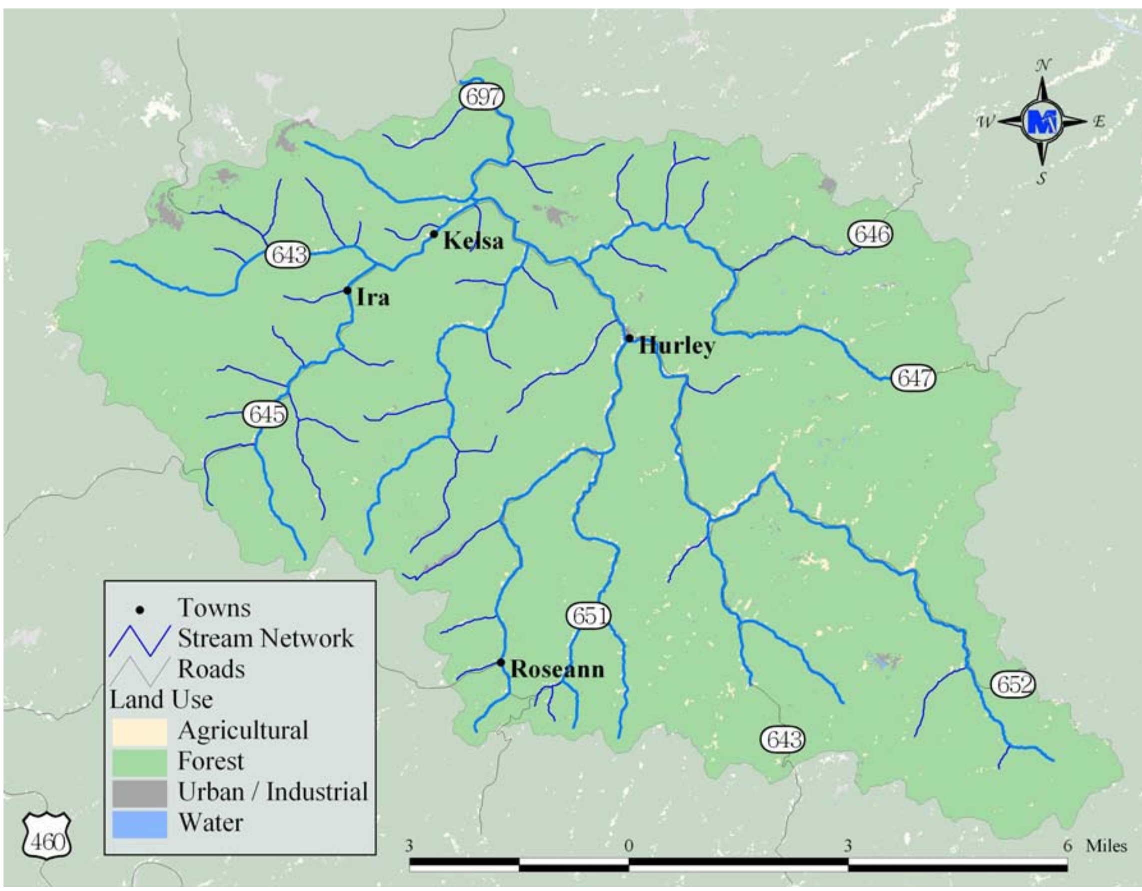

Figure 3.1 Land uses in the Knox Creek watershed.

The estimated human population within the Knox Creek drainage area currently is 3,878. Buchanan County is home to 329 species of wildlife including 50 types of mammals (*e.g.,* beaver, raccoon, and white - tailed deer) and 146 types of birds (*e.g.,* wood duck, wild turkey) (VDGIF, 2005).

For the period 1955 to 2004, the Knox and Pawpaw watersheds received average annual precipitation of approximately 44.58 inches, with 53% of the precipitation occurring during the May through October growing season (SERCC, 2005). Average annual snowfall is 17.3 inches with the highest snowfall occurring during January (SERCC, 2005). Average annual daily temperature is 55.6 ºF. The highest average daily temperature of 87.1 ºF occurs in July, while the lowest average daily temperature of 23.3 ºF occurs in January (SERCC, 2005).

3.2 Assessment of Point Sources

Nine non-mining point sources are permitted in the Knox Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Figure 3.2 shows the permitted locations. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 mL. Currently, these permitted dischargers are expected not to exceed the 126 cfu/100mL *E. coli* standard. Table 3.2 summarizes data from these point sources.

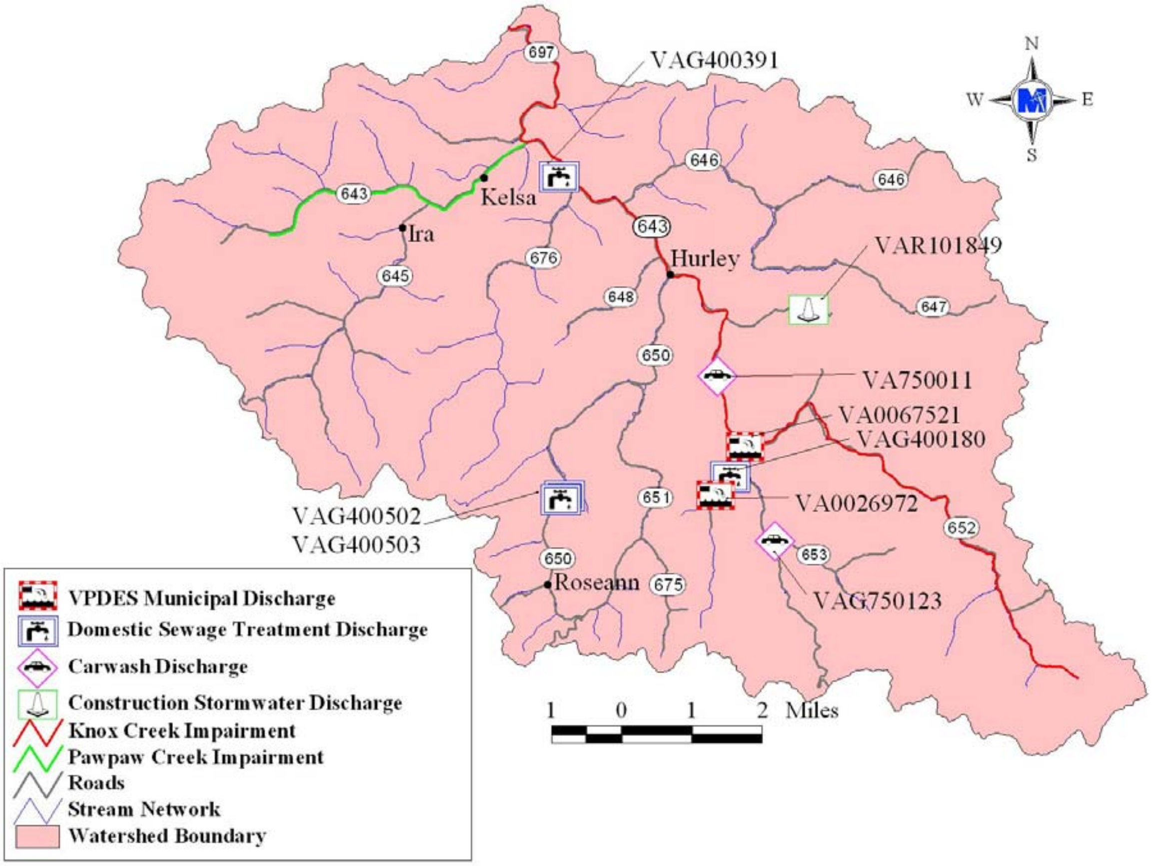

Figure 3.2 Location of VADEQ permitted point sources in the Knox Creek watershed.

Table 3.2 Summary of VADEQ permitted point sources in the Knox Creek watershed.

Facility Name	Permit No	Recorded Flow (MGD)[1]	Design Flow (MGD)	Permitted For Fecal Control	Active During Modeling Time Periods[2]	Receiving Stream
Buchanan County Hurley High School	VA0026972	0.007	0.008	YES	YES	Straight Fork (until 1999); Right Fork (currently)
Buchanan County Hurley Middle School	VA0067521	0.0057	0.017	YES	YES	Right Fork
Domestic discharge	VAG400180	0.001	0.001	YES	YES	Straight Fork
Domestic discharge	VAG400391	0.001	0.001	YES	YES	Knox Creek
Hurley Heights I	VAG400502	0.001	0.001	YES	YES	Lester Fork
Hurley Heights II	VAG400503	0.001	0.001	YES	YES	Lester Fork
Rebel Den Dine & Shine	VAG750011	0.005	0.005	NO	YES	Knox Creek
Pit Stop - Wolford	VAG750123	0.005	0.005	NO	YES	Right Fork
VDOT Lebanon	VAR101849	NA	NA	NO	YES	Laurel Fork

[1]NA = Not applicable

[2]Modeling time periods = HSPF Hydrology Calibration, HSPF FC Calibration, HSPF TDS Calibration, GWLF Modeling

3.3 Assessment of Nonpoint Sources

In the Knox Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, livestock, wildlife, and pets. Sources were identified and enumerated. MapTech collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process, and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (section 2.6.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

In U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank or a cesspool, or the sewage is disposed of in some other way. The Census category "Other

Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing sewage directly to the stream. Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using Geographic Information Systems (GIS) (Table 3.3).

Table 3.3 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2005 in the Knox and Pawpaw Creek watershed.

Stream	State	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Knox Creek	VA	3,190	1,533	0	1,387	146
	KY	0	0	0	0	0
Pawpaw Creek	VA	687	358	0	334	24
	KY	321	127	0	113	14

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

Due to discussions at public meetings, it was determined that there are no sanitary sewer systems serving any of the Knox Creek watershed.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 mL. An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

3.3.2 Pets

Among pets, cats, dogs, and roosters are the predominant contributors of fecal coliform in the watershed. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. The number of domestic roosters was estimated by the Big Sandy Soil and Water Conservation District. A summary of the data collected is given in Table 3.4 along with the domestic animal populations.

Table 3.4 Domestic animal population density, total population, waste load, and fecal coliform density for the Knox Creek watershed.

Type	**State**	**Population Density** (an/house)	**Total Population** (# an)	**Waste load** (g/an-day)	**FC Density** (cfu/g)
Dog	VA	0.534	1,010	450	480,000
	KY	0.534	68	450	480,000
Cat	VA	0.598	1,131	19.4	9
	KY	0.598	76	19.4	9
Rooster[1]	VA	0.325	615	0.26	586,000
	KY	0.325	27	0.26	586,000

[1] Based on poultry layer waste load production

3.3.3 Livestock

The predominant types of livestock in the Knox Creek watershed are cattle although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Big Sandy Soil and Water Conservation

District (BSSWCD), landowner input, watershed visits, and review of all publicly available information on animal type and approximate numbers known to exist within Buchanan County. Table 3.5 gives a summary of livestock populations in the Knox Creek watershed. Values of fecal coliform density of livestock sources were based on sampling previously performed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.6.

Table 3.5 Livestock populations in the Knox Creek watershed.

State	Total Cattle	Beef Cattle	Dairy	Hog	Horse	Sheep
VA	73	44	1	1	71	3
KY	0	0	0	0	0	0

Table 3.6 Average fecal coliform densities and waste loads associated with livestock for the Knox Creek watershed.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Beef stocker (850 lb)	51.0	101,000
Beef calf (350 lb)	21.0	101,000
Dairy milker (1,400 lb)	120.4	271,329
Dairy heifer (850 lb)	70.0	271,329
Dairy calf (350 lb)	29.0	271,329
Hog (135 lb)	11.3	400,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams. No confined animal facilities were identified in the Knox Creek watershed, so only the second and third pathways were considered.

All livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for beef cattle was verified by BSSWCD (Table 3.7). Horses and sheep were assumed to be in pasture 100% of the time. The average amount of time spent by beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Table 3.7.

Table 3.7 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day for the Knox Creek watershed.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.4 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF, FWS and Mayhorn, and are listed in Table 3.8 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Mayhorn, 2005, Norman, 2004; and Rose and Cranford, 1987). The numbers of animals estimated to be in the Knox Creek watershed are reported in Table 3.9. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996; and Yagow, 1999). Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.10. Table 3.11 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife waste performed by MapTech. The only value that was not obtained from MapTech sampling was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling.

Table 3.8 Wildlife population density in Buchanan county (animal / acre of primary habitat).

County	Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
Buchanan	0.0037	0.0079	0.0	0.0027	2.7500	0.0703	3.8000

Table 3.9 Wildlife populations in the Knox Creek watershed.

State	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
VA	181	397	0	15	3,274	675	254
KY	14	30	0	0	284	59	14

Table 3.10 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife for the Knox Creek watershed.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Duck	3,500	75

Table 3.11 Wildlife fecal production rates and habitat for the Knox Creek watershed.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining land use areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining land use areas
Duck	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

[1]Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2]Waste load for domestic turkey (ASAE, 1998).
[3]Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of the fecal bacteria TMDL for the Knox Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate fecal coliform existing conditions and to perform fecal bacteria TMDL allocations. The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities can be explicitly accounted for in the model. The use of HSPF allowed for consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (each referred to in the model as a RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 HSPF Model Setup

Daily precipitation data was available within the Knox Creek watershed at the Hurley 4S NCDC Coop station #444180 (Figure 4.1). Missing values were filled with daily precipitation from the Grundy NCDC Coop station #443640. The resulting daily precipitation was disaggregated into hourly precipitation using the distribution from hourly data at the Hurley 4S NCDC Coop station #444180.

To adequately represent the spatial variation in the Knox Creek watershed, the drainage area was divided into 24 subwatersheds (Figure 4.1). All subwatersheds contribute to Knox Creek; subwatersheds 20, 21, 22, and 23 contribute to Pawpaw Creek. Because Pawpaw Creek drains to Knox Creek and only Knox Creek is impaired for fecal bacteria, in this chapter and Chapter 5 the watershed will be referred to as the Knox Creek watershed.

The rationale for choosing subwatersheds was based on the availability of surface flow data and water quality data (fecal coliform and TDS), which were available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic depiction of hydrologic factors in the watershed.

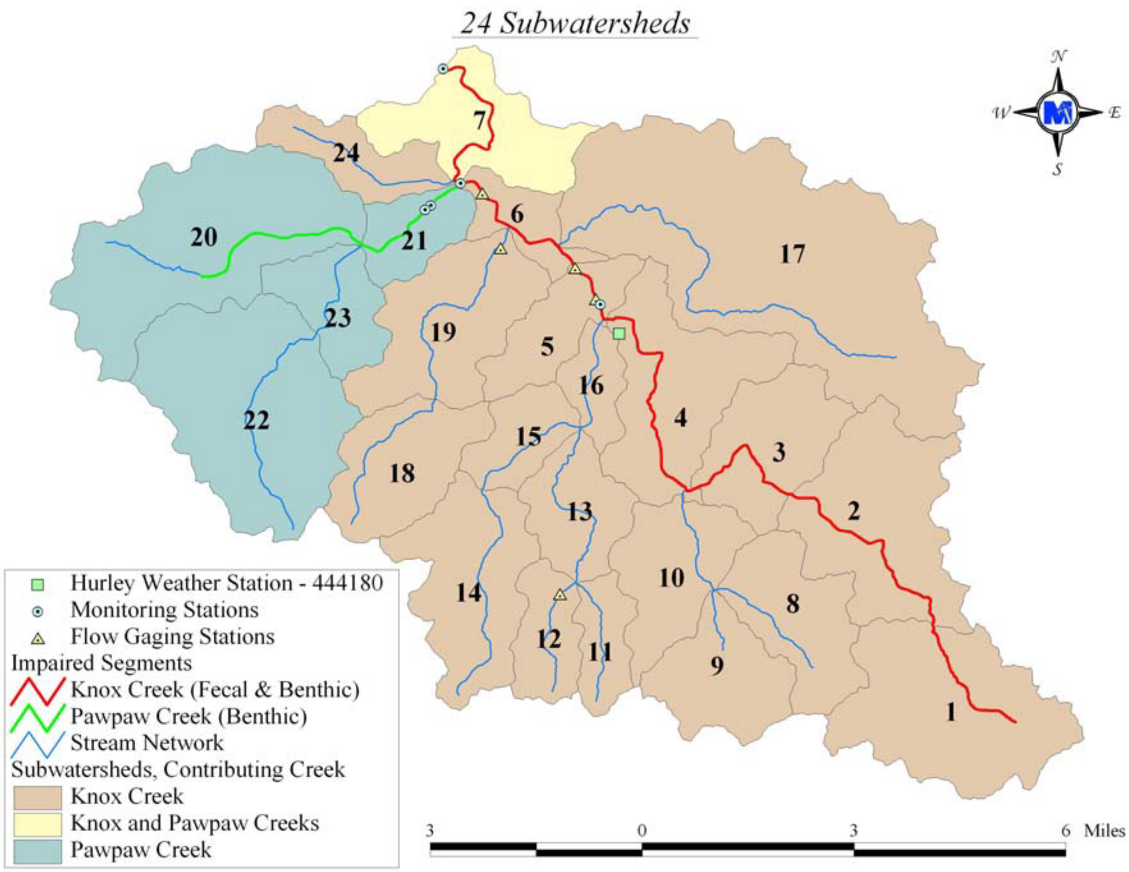

Figure 4.1 Subwatersheds delineated for modeling and location of water quality and flow monitoring sites in the Knox Creek watershed.

Using MRLC USGS 7.5 Minute Maps, U.S. Census Bureau TIGER (Topologically Integrated Geographic Encoding and Referencing), and DMME data, land use types in the modeled watersheds were identified. The land use types were consolidated into ten categories based on similarities in hydrologic features (Tables 4.1 and 4.2). Within each subwatershed, up to the ten land use categories were represented. Each land use had parameters associated with it that described the hydrology of the area (*i.e.,* average slope length) and the behavior of pollutants. These land use types are represented in HSPF as PERLNDs and IMPLNDs. Impervious areas are represented in three IMPLND types, while there are ten PERLND types, each with parameters describing a particular land use (Table 4.1 and 4.2). Some IMPLND and PERLND parameters (*i.e.,* slope length) vary with the particular subwatershed in which they are located. Others (*i.e.*, upper zone storage) vary with season to account for plant growth, die-off, and removal.

Table 4.1 Land use categories for the Knox Creek watershed.

TMDL Land use Categories	Pervious / Impervious (%)	Land use Classifications (MRLC Class No. where applicable)
Abandoned Mine Land	Pervious (100%)	Land disturbed by mining operations before 1978 and not reclaimed
Active Mining	Pervious (70%) Impervious (30%)	Land disturbed by mining operations
Cropland	Pervious (100%)	Row Crops (82)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Livestock Access	Pervious (100%)	Pasture/Hay (81) near streams
Pasture	Pervious (100%)	Pasture/Hay (81)
Reclaimed	Pervious (100%)	Land regraded and revegetated after mining operations
Residential	Pervious (80%) Impervious (20%)	Low Intensity Residential (21) High Intensity Residential (22)
Roads – Salt applied	Impervious (100%)	Paved roads
Water	Pervious (100%)	Open Water (11) National Hydrography Data

Table 4.2 Contributing land use area for the Knox Creek watershed.

Land use	Knox Creek watershed (acres)
Virginia:	
Active Mining	787
Abandoned Mine Land	2,085
Cropland	432
Forest	47,450
Livestock Access	16
Pasture	149
Reclaimed	399
Residential	43
Roads – Salt applied	191
Water	598
Kentucky:	
Active Mining	371
Abandoned Mine Land	38
Cropland	0
Forest	3,490
Pasture	7
Reclaimed	30
Roads – Salt applied	0
Water	28
Total	**56,114**

For the purpose of modeling the hydrology and pollutant loads from AML, only sites identified outside boundaries of current permitted mining permits were modeled as AML. It was assumed that AML located in current permit areas would be reclaimed when the permit is released.

4.2.1 Mine Land Hydrology Model Setup (HSPF)

Surface mining requires sediment/runoff retention ponds, which are regulated through the Virginia DMME. The outflow from these ponds is modeled through an additional RCHRES for each subwatershed with a retention pond. The disturbed land area contributing to these ponds was accounted for in the RCHRES. The average revegetated land per year was an input to the model to represent average reclamation efforts completed each year. The locations of these ponds in the Knox Creek watershed during the hydrologic calibration time period are shown in Figure 4.2

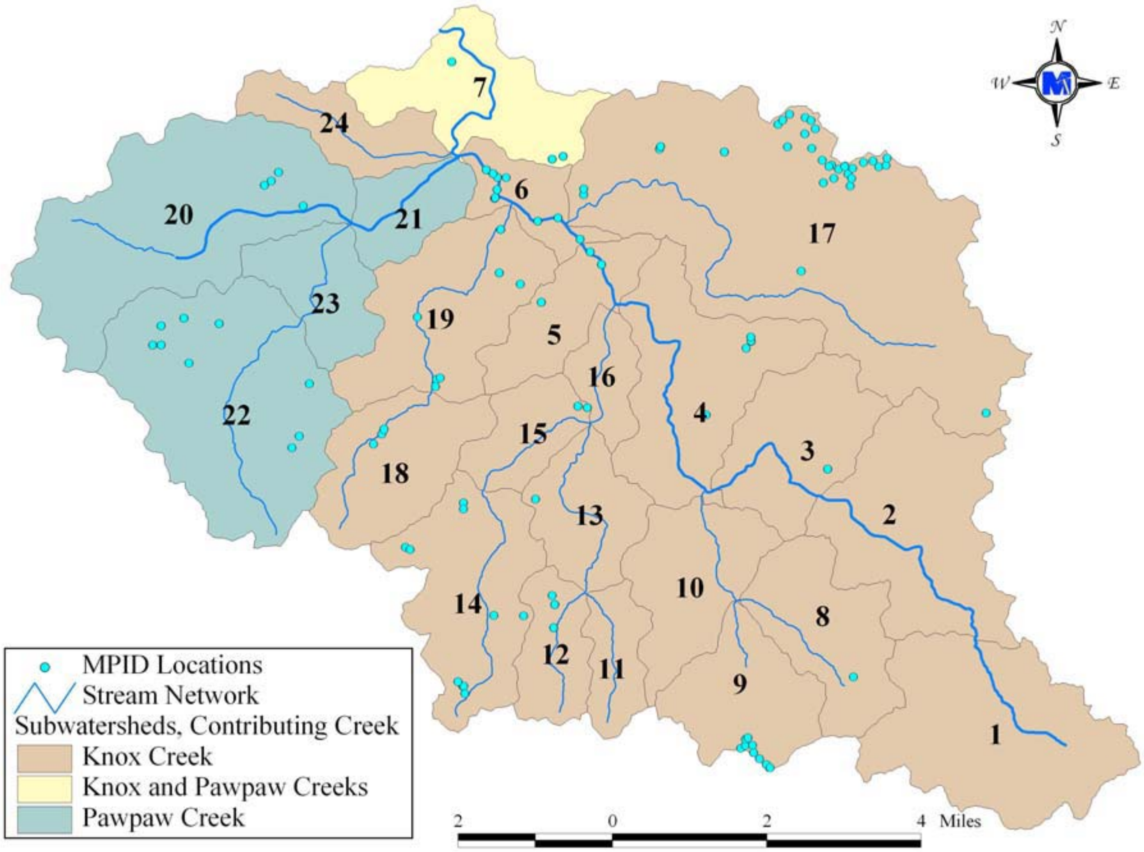

Figure 4.2 Surface runoff retention ponds operational during the calibration time period in the Knox Creek watershed.

4.2.2 Fecal Coliform Water Quality Model Setup (HSPF)

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (fecal matter deposited directly on land), die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of

HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation - Fecal Coliform

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport varies with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* population). Depending on the time-frame of the simulation being run, different numbers should be used. For modeling Knox Creek fecal coliform loads, data representing 1996 were used for the water quality calibration period (1994-1997). Data representing 2005 were used for the allocation runs in order to represent current conditions for the impairment.

4.3.1 Point Sources

For permitted point discharges (Table 3.2 and Figre 3.2), specific flow data over time provided by VADEQ was used during hydrology and FC calibration. Design flow capacities were used for allocation runs (Chapter 5). For allocations, the design flow rate was combined with a fecal coliform concentration of 200 cfu/100 mL (for discharges permitted for fecal control) to ensure that compliance with state water quality standards can be achieved even if the facilities were discharging at the maximum allowable flow rate. Figure 3.2 shows the location of all permits active during the modeling time periods. Table 3.2 gives detail of each permited discharge.

Nonpoint sources of pollution that were not driven by runoff are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

Through GIS, the number of septic systems in the subwatersheds modeled for the Knox Creek watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential land use types. Each land use area was assigned a number of septic systems based on census data. It was estimated that a total of 1,667 septic systems were in the Knox Creek watershed in 1996. During allocation runs, the number of households was projected to 2005 values (based on current Buchanan County growth rates; USCB, 2000) resulting in 1,683 septic systems in the Knox Creek watershed (Table 4.3). Although the table is broken into a Knox and Pawpaw Creek data, only Knox Creek is impaired for fecal bacteria.

Table 4.3 Estimated failing septic systems and straight pipes (2005) for the Knox Creek watershed.

Impaired Segment	State	Total Septic Systems	Failing Septic Systems	Straight Pipes
Knox Creek	VA	1,387	360	146
	KY	0	0	0
Pawpaw Creek	VA	334	89	24
	KY	113	46	14

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of TMDLs for the Knox Creek watershed (Reneau, 2000). Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges such as straight pipes. Corresponding block data and subwatershed boundaries were intersected using GIS to determine an estimate of uncontrolled discharges in each subwatershed (Table 4.3). Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model. Total dissolved solids (TDS) concentration from human waste for each discharge was estimated as 500 mg/L (Metcalf and Eddy, 1991). A total suspended solids concentration from human waste was estimated as 320 mg/L (Lloyd, 2004). The methods of incorporating TDS and TSS loads into the benthic TMDLs are discussed further in Chapter 10.

4.3.2.3 Sewer System Overflows

During the model calibration and allocation periods, there were no sewer overflows in the Knox Creek watershed, as there is no sanitary sewer system.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Due to the lack of confined animal facilities in these watersheds, only deposition on land and direct deposition to streams are accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers for 2005 were used for calibration and allocation for Knox Creek. The numbers are based on data provided by Big Sandy SWCD and verbal communication with the local community. Growth rates were taken into account in Buchanan County as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995 and VASS, 2002). The fecal coliform density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.7).

4.3.3.1 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse, sheep, and hog) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land use type was area-weighted.

4.3.3.2 Direct Deposition to Streams

The amount of waste deposited in streams by livestock each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% was treated as manure deposited on land. However, applying it in a specific land use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that no biosolids applications have occurred within the Knox Creek watershed.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (section 3.3.4). Examples of these layers are shown in Figure 4.3. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.12). For all animals other than beaver, it was estimated that 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1994–1997) projections were made to wildlife populations, as there was no available data to support such adjustments.

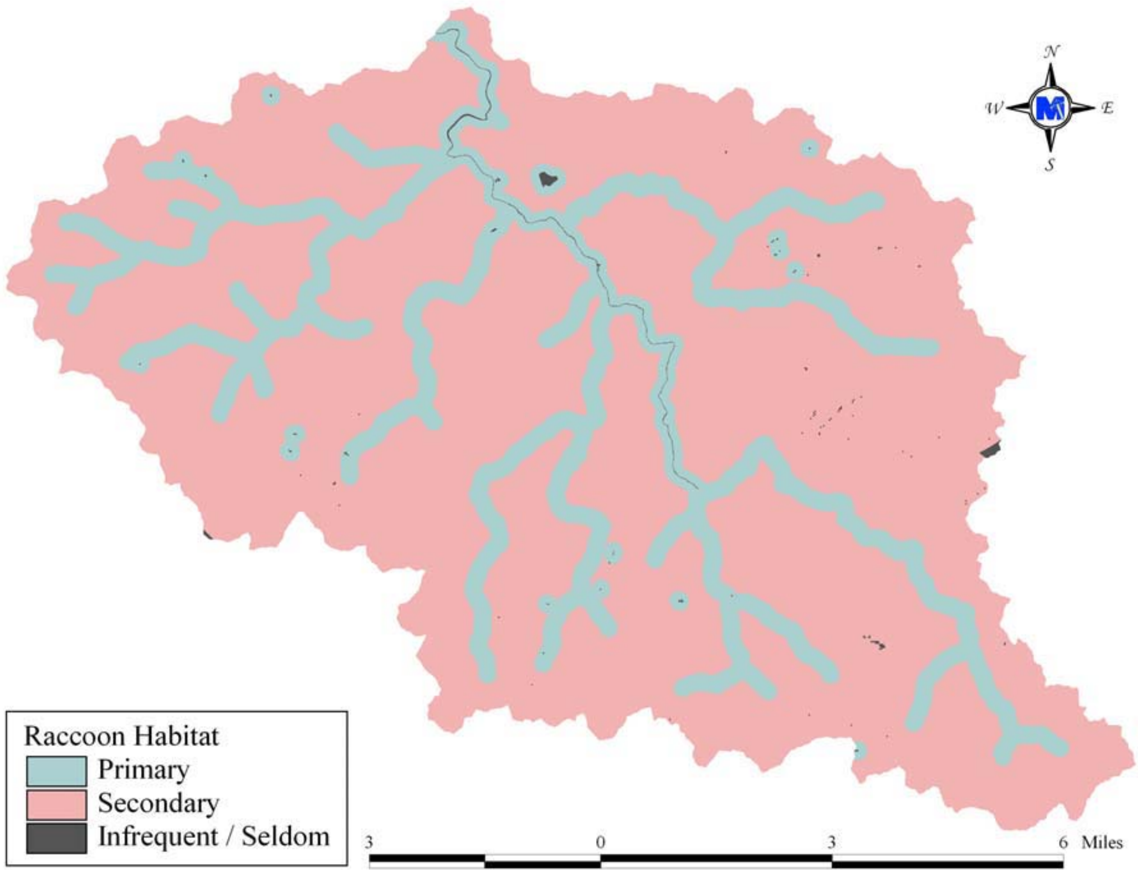

Figure 4.3 Example of raccoon habitat layer in the Knox Creek watershed as developed by MapTech.

4.3.6 Pets

Cats, dogs and roosters were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in section 3.3.2. Waste from pets was distributed in the residential land uses. The locations of households were taken from census reports from 1990 and 2000 (USCB, 1990, 2000). Using GIS, the land use and household layers were overlaid, which resulted in number of households per land use. The number of animals per land use was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals of both cats and dogs. The waste load was assumed not to vary seasonally. The population figures for cats and dogs were projected from 1990 data to 1996 and 2005.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at locations that were representative of the stream for the modeled subwatersheds.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.4). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

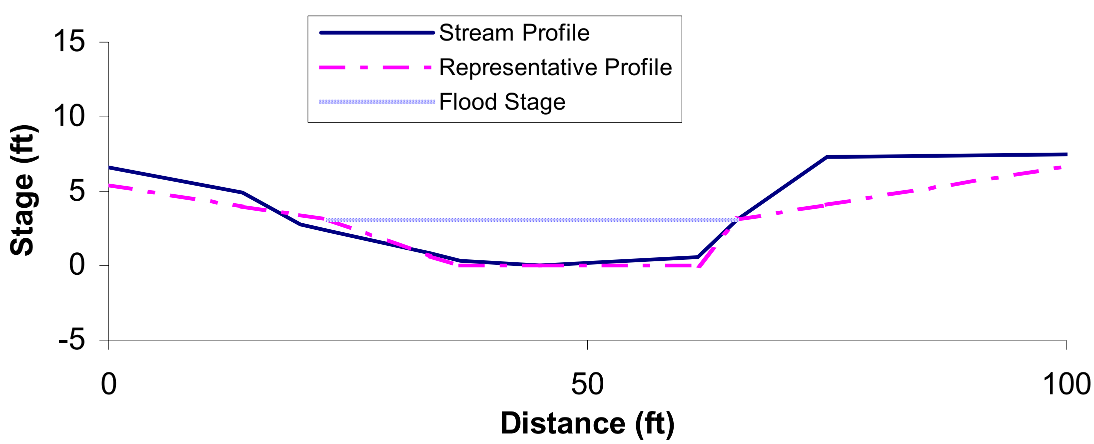

Figure 4.4 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (*i.e.,* Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, then these were added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness coefficient for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS data in the watershed, which included elevation from the National Elevation Dataset (NED) and a stream-flow network developed from high resolution National Hydrologic Dataset (NHD) data and accumulated flow derived from GIS. These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.4). The F-tables consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the stream reach or reservoir in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second. The HSPF model calculates discharge based on volume of water in the reach. For the case of impoundments that were modeled, a minimum volume was set based on design parameters of the pond. During periods of no discharge from the pond, the only pathway for removal of water from the pond was evaporation.

Table 4.4 Example of an F-table calculated for the HSPF Model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Discharge (cfs)
0	0	0	0
0.35	3.09	25.63	0.04
0.7	12.96	39.76	23.87
1.05	13.64	52.06	45.84
1.4	14.37	65.89	72.44
1.75	15.15	81.35	102.9
2.1	15.98	98.56	136.69
2.45	16.87	117.64	173.39
2.8	17.8	138.71	212.7
3.15	18.78	161.86	254.34
3.5	19.82	187.24	298.12
3.85	19.87	190.67	343.86
9.5	20.75	248.72	1275.84
15.15	21.63	311.76	2464.83
20.8	22.52	379.77	3861.02
26.45	23.4	452.77	5454.18

4.5 Selection of Representative Modeling Periods

Selection of the modeling periods was based on three factors: the degree of land-disturbing activity, availability of data (stream flow and water quality), and the need to represent critical hydrological conditions. Using these criteria, modeling periods were selected for hydrology calibration, water quality calibration, and modeling of allocation scenarios.

Much of the data used to develop the inputs for modeling water quality is time-dependent. Depending on the time frame of the simulation being run, the model was varied appropriately. Based on a review of mine permit anniversary reports, it was evident that significant landform alterations started to occur in the Knox Creek watershed in 1998 (Figure 4.5). The hydrographic landscape of the watersheds was relatively stable during the period from 1994 to 1997.

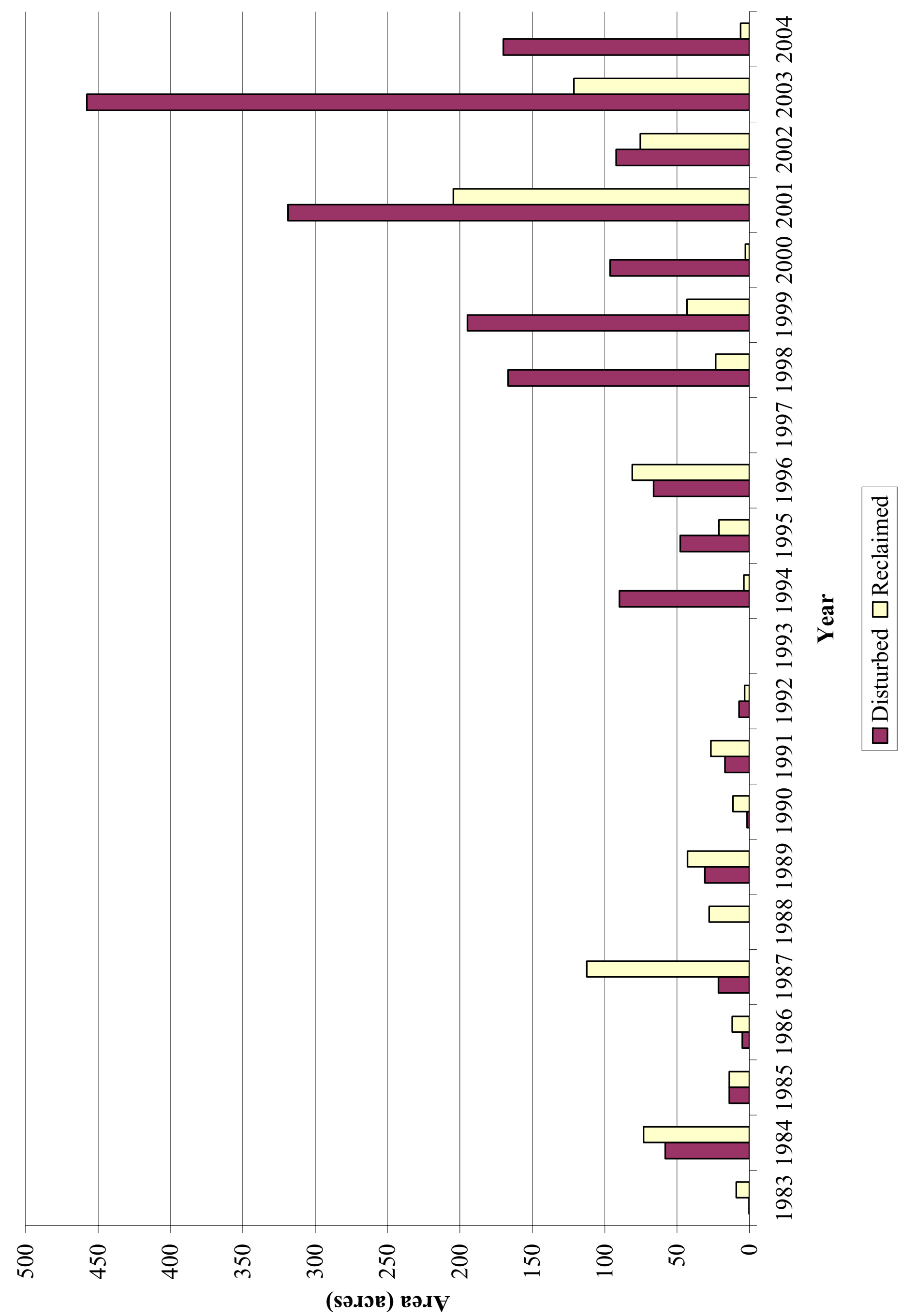

Figure 4.5 Annual disturbed and reclaimed land by mining operations in the Knox Creek watershed.

There are no continuous USGS flow stations in the Knox Creek watershed. Instantaneous stream flow data was available at DMME monitoring point identification stations (MPIDs) throughout the watershed from 1/18/1995 to 8/5/2005.

As shown in the critical conditions section (section 2.4, Figure 2.1), there is no critical flow level at VADEQ Station 6AKOX006.52, where the most bacteria data was collected. This indicates that the modeling time periods must include low and high stream flow regimes.

The hydrologic modeling period selected was 10/1/1994 to 9/30/1997 based on the stability of the land during this time, the availability of data, and the need to represent critical hydrologic conditions. Data representing this period were used to develop the HSPF hydrologic model used in this study.

A representative period for fecal coliform calibration for Knox Creek was selected with consideration given to the hydrology calibration period, availability of water quality data, and the VADEQ assessment period from January 1996 through December 2000 that led to the inclusion of the Knox Creek segment on the *2002 303(d) Report on Impaired Waters* (VADEQ, 2002). Fecal coliform and *E. coli* data for Knox Creek were available in the period from 2/1/1980 through 6/1/2004 at various locations throughout the watershed. With these criteria in mind, the modeling period for fecal coliform water quality calibration was selected as 10/1/1993 through 9/30/1998 (Table 4.5). Fecal coliform water quality validation was not performed for Knox Creek because a stable time period was chosen for modeling and all observed data collected during this time period was used for calibration. It was determined that using available data for calibration would result in a more accurate model.

Table 4.5 Summary of modeling time periods for the Knox Creek watershed.

Impairment	Hydrology Calibration	Water Quality (FC) Calibration
Knox Creek	10/1/1994 to 9/30/1997	10/1/1993 to 9/30/1998

The allocation precipitation time periods were selected to coincide with the calibration time periods. Modeling during the calibration periods provides the highest confidence in allocation results.

4.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

Sensitivity analyses were run on both hydrologic and water quality parameters. The parameters adjusted for the hydrologic sensitivity analyses are presented in Tables 4.6, with base values for the model runs given. The parameters were typically adjusted to -50%, -10%, 10%, and 50% of the base value. Where an increase of 50% exceeded the maximum value for the parameter, the maximum value was used and the parameters increased over the base value were reported. The model was run for the hydrology calibration time period (water years 1995 through 1997). The hydrologic quantities of greatest interest in modeling NPS pollutants are those that govern peak (high) flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of NPS pollutants from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and AGWRC (Groundwater Recession Rate). To a lesser extent peak flows were sensitive to LZSN (Lower Zone Storage) and UZSN (Upper Zone Storage). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the Low Flows and Summer Flow Volume statistics) were AGWRC, INFILT, LZSN, LZETP (Lower Zone Evapotranspiration) and, to a lesser extent, CEPSC (interception). The responses of these and other hydrologic outputs are reported in Table 4.7.

Table 4.6 Base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
AGWRC	Active Groundwater Coefficient	1/day	0.98
BASETP	Base Flow Evapotranspiration	---	0.01
CEPSC	Interception Storage Capacity	in	0.01-0.2
DEEPFR	Fraction of Deep Groundwater	---	0.01
INFILT	Soil Infiltration Capacity	in/hr	0.001-0.18
INTFW	Interflow Inflow	---	1.0
KVARY	Groundwater Recession Coefficient	1/day	0.0
LZSN	Lower Zone Nominal Storage	in	2.0-3.704
LZETP	Lower Zone Evapotranspiration	---	0.01-0.8
NSUR	Manning's *n* for Overland Flow	---	0.1
UZSN	Upper Zone Storage Capacity	in	0.05-1.185

Table 4.7 Sensitivity analysis results for hydrologic model parameters (% change).

Model Parameter	Parameter Change (%)	Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	-0.13	9.60	-36.55	7.66	-5.58	-22.17	15.48	27.98
AGWRC[1]	0.92	-0.06	4.99	-23.08	7.21	-4.69	-18.93	11.92	24.91
AGWRC[1]	0.96	0.05	2.05	-10.64	5.08	-2.48	-11.44	5.41	13.94
AGWRC[1]	0.999	-26.72	-11.86	-39.54	-30.02	-24.19	-19.94	-31.30	-23.86
BASETP	-50	0.14	-0.24	0.90	-0.07	0.22	0.86	-0.27	0.01
BASETP	-10	0.03	-0.05	0.18	-0.01	0.04	0.17	-0.05	0.00
BASETP	10	-0.03	0.05	-0.18	0.02	-0.04	-0.17	0.06	0.09
BASETP	50	-0.13	0.24	-0.91	0.08	-0.22	-0.85	0.27	0.40
DEEPFR	-50	0.29	0.11	0.50	0.26	0.25	0.39	0.37	0.22
DEEPFR	-10	0.06	0.02	0.10	0.05	0.05	0.08	0.07	0.04
DEEPFR	10	-0.06	-0.02	-0.10	-0.05	-0.05	-0.08	-0.07	-0.04
DEEPFR	50	-0.29	-0.11	-0.50	-0.26	-0.25	-0.39	-0.37	-0.22
INFILT	-50	-0.08	23.08	-24.39	5.43	-2.22	-11.95	3.70	6.92
INFILT	-10	-0.01	3.30	-3.72	1.01	-0.41	-2.02	0.52	0.96
INFILT	10	0.01	-2.96	3.31	-0.97	0.37	1.89	-0.41	-0.80
INFILT	50	0.01	-12.25	13.53	-4.47	1.44	8.66	-1.43	-2.93
INTFW	10	0.00	-0.85	0.08	-0.05	0.07	-0.02	-0.01	0.01
INTFW	50	0.00	-3.04	0.21	-0.15	0.18	-0.07	-0.02	0.09
INTFW	100	-0.01	-4.12	0.24	-0.14	0.19	-0.09	-0.02	0.17
INTFW	200	0.00	-4.85	0.18	-0.11	0.21	-0.19	0.01	0.24
LZSN	-50	2.96	9.08	-3.13	7.03	-1.08	-9.23	14.29	2.26
LZSN	-10	0.52	1.40	-0.27	1.30	-0.08	-1.46	1.98	0.61
LZSN	10	-0.49	-1.30	0.23	-1.24	0.04	1.31	-1.66	-0.56
LZSN	50	-2.15	-5.69	1.13	-5.70	-0.12	5.46	-5.94	-2.42
CEPSC	-50	1.03	-2.17	6.31	0.32	0.84	3.60	0.53	-0.29
CEPSC	-10	0.15	-0.39	1.09	0.07	0.04	0.81	-0.06	0.11
CEPSC	10	-0.15	0.22	-0.79	-0.07	-0.15	-0.60	0.10	-0.08
CEPSC	50	-0.79	1.39	-4.76	-0.10	-0.85	-3.08	0.05	0.29
LZETP	-50	4.98	4.93	6.20	3.37	1.50	4.94	15.96	1.82
LZETP	-10	0.47	0.39	0.74	0.44	0.08	0.28	1.53	0.07
LZETP	10	-0.37	-0.30	-0.62	-0.36	-0.08	-0.24	-1.12	0.20
LZETP	50	-2.91	-2.37	-4.87	-1.64	-0.70	-5.05	-8.30	-0.31
MANNING	-50	0.04	0.54	-0.83	0.40	-0.03	-0.74	0.13	0.28
MANNING	-10	0.01	0.22	-0.17	0.22	-0.12	-0.11	-0.06	0.08
MANNING	10	-0.01	-0.26	0.17	-0.18	0.13	0.11	-0.05	-0.06
MANNING	50	-0.05	-1.04	0.71	-0.42	0.14	0.50	-0.18	-0.20
UZSN	-50	1.92	4.85	-0.45	1.68	0.00	1.09	7.34	3.28
UZSN	-10	0.36	0.84	0.09	0.32	-0.05	0.28	1.37	0.54
UZSN	10	-0.34	-0.74	-0.15	-0.37	0.08	-0.27	-1.20	-0.50
UZSN	50	-1.49	-3.35	-0.91	-1.87	0.60	-1.14	-5.37	-2.10

[1]Numbers represent actual values used for variable -- base value = 0.98

The model was run during the corresponding water quality calibration time period for the fecal coliform water quality sensitivity analysis. The three parameters impacting the model's water quality response (Table 4.8) were increased and decreased by amounts that were consistent with the range of values for the parameter.

Since the water quality standard for fecal coliform bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric-mean fecal coliform concentration. A monthly geometric mean was calculated for all months during the simulation period, and the values for each month were averaged. Deviations from the base run are given in Table 4.9. All results are plotted by month in Figure 4.6 through Figure 4.8.

In addition to analyzing the sensitivity of the model response to changes in model parameters, the response of the model to changes in land-based and direct loads was analyzed. The impacts of land-based and direct load changes on the annual load are presented in Figure 4.9, while impacts on the monthly geometric mean are presented in Figures 4.10 and 4.11.

It is evident from Figure 4.9 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. For Knox Creek the magnitude of this relationship differs greatly between land applied and direct loadings. As a 100% increase in the land-applied loads results in an increase of 96.5% in-stream loads, while a 100% increase in direct loads results in an increase of only 2.9% for in-stream loads.

The sensitivity analysis of geometric mean concentrations in Figures 4.10 and 4.11 showed that direct loads had the greatest impact, with land-applied loads having a lesser, but measurable impact.

Table 4.8 Base parameter values used to determine water quality model response for Knox Creek.

Parameter	Description	Units	Base Value
FSTDEC	In-stream First Order Decay Rate	1/day	0.5
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	35*
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0.08-0.38*

*The water land use had a WSQOP and MON-SQOLIM value of 0.00.

Table 4.9 Percent change in average monthly *E. coli* geometric mean for the years 1998-2003 for Knox Creek.

Model	Parameter Change	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2003											
Parameter	(%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	6.46	6.07	5.74	5.92	5.89	6.53	6.40	6.18	6.78	6.85	7.15	6.50
FSTDEC	-10	1.21	1.15	1.09	1.13	1.13	1.25	1.22	1.18	1.29	1.30	1.36	1.23
FSTDEC	10	-1.19	-1.13	-1.07	-1.11	-1.10	-1.23	-1.20	-1.15	-1.27	-1.28	-1.33	-1.20
FSTDEC	50	-5.68	-5.44	-5.15	-5.34	-5.34	-5.91	-5.78	-5.55	-6.10	-6.14	-6.40	-5.78
MON-SQOLIM	-50	-6.09	-3.70	-3.18	-2.96	-3.28	-4.92	-6.00	-3.62	-8.52	-6.09	-12.08	-6.57
MON-SQOLIM	-25	-2.31	-1.29	-1.11	-1.04	-1.15	-1.75	-2.24	-1.31	-3.36	-2.33	-5.16	-2.46
MON-SQOLIM	50	2.83	1.37	1.19	1.10	1.21	1.87	2.53	1.41	4.07	2.82	7.02	2.91
MON-SQOLIM	100	4.55	2.09	1.82	1.67	1.86	2.88	3.97	2.19	6.49	4.53	11.71	4.63
WSQOP	-50	3.94	8.25	4.68	4.39	6.27	4.77	3.22	3.06	4.10	3.94	7.44	6.52
WSQOP	-10	0.67	1.44	0.77	0.79	1.17	0.87	0.60	0.52	0.75	0.69	1.47	1.28
WSQOP	10	-0.40	-0.86	-0.45	-0.48	-0.71	-0.53	-0.37	-0.31	-0.46	-0.42	-0.90	-0.79
WSQOP	50	-1.84	-3.92	-1.97	-2.23	-3.36	-2.53	-1.81	-1.41	-2.16	-1.90	-4.31	-3.82

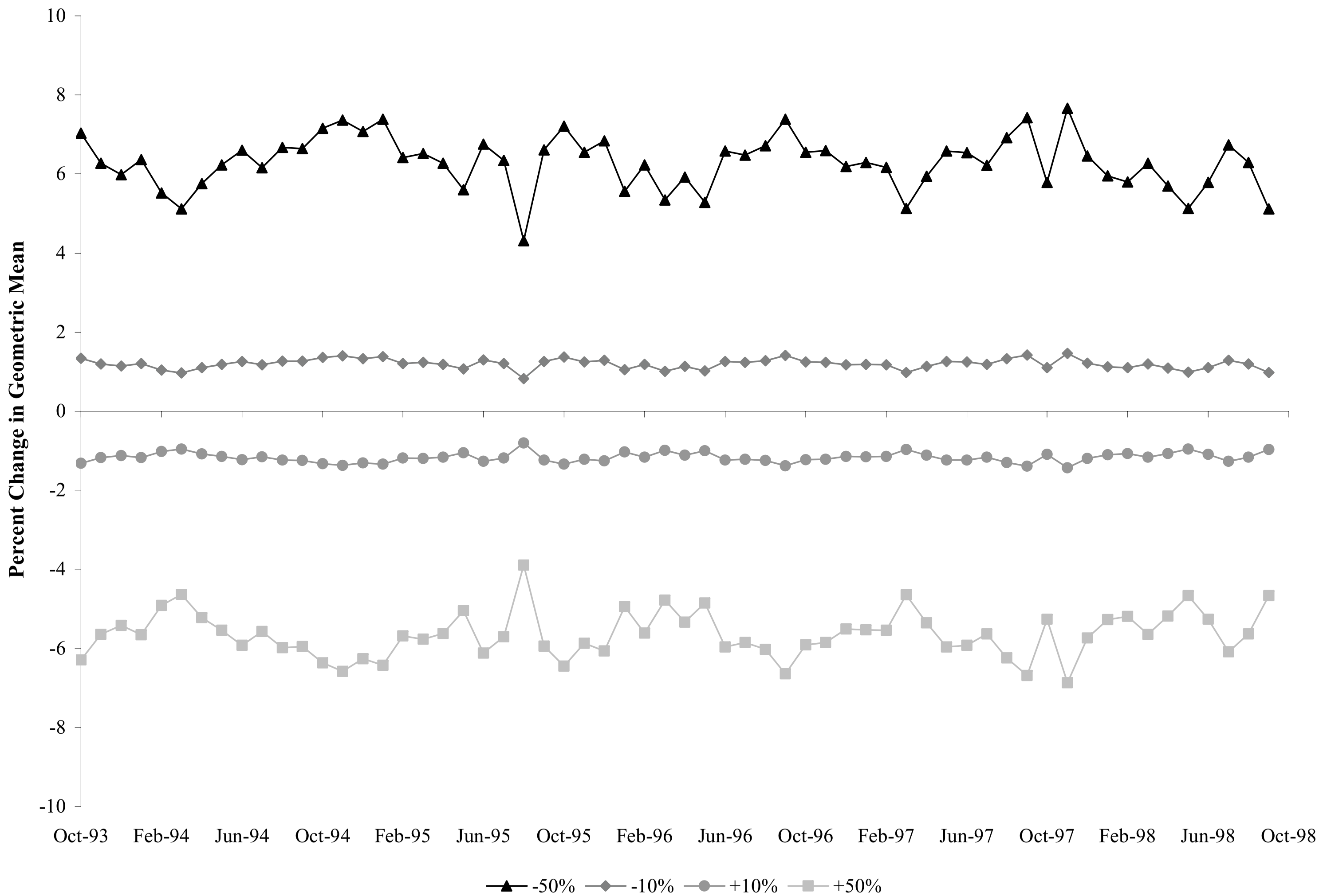

Figure 4.6 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Knox Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

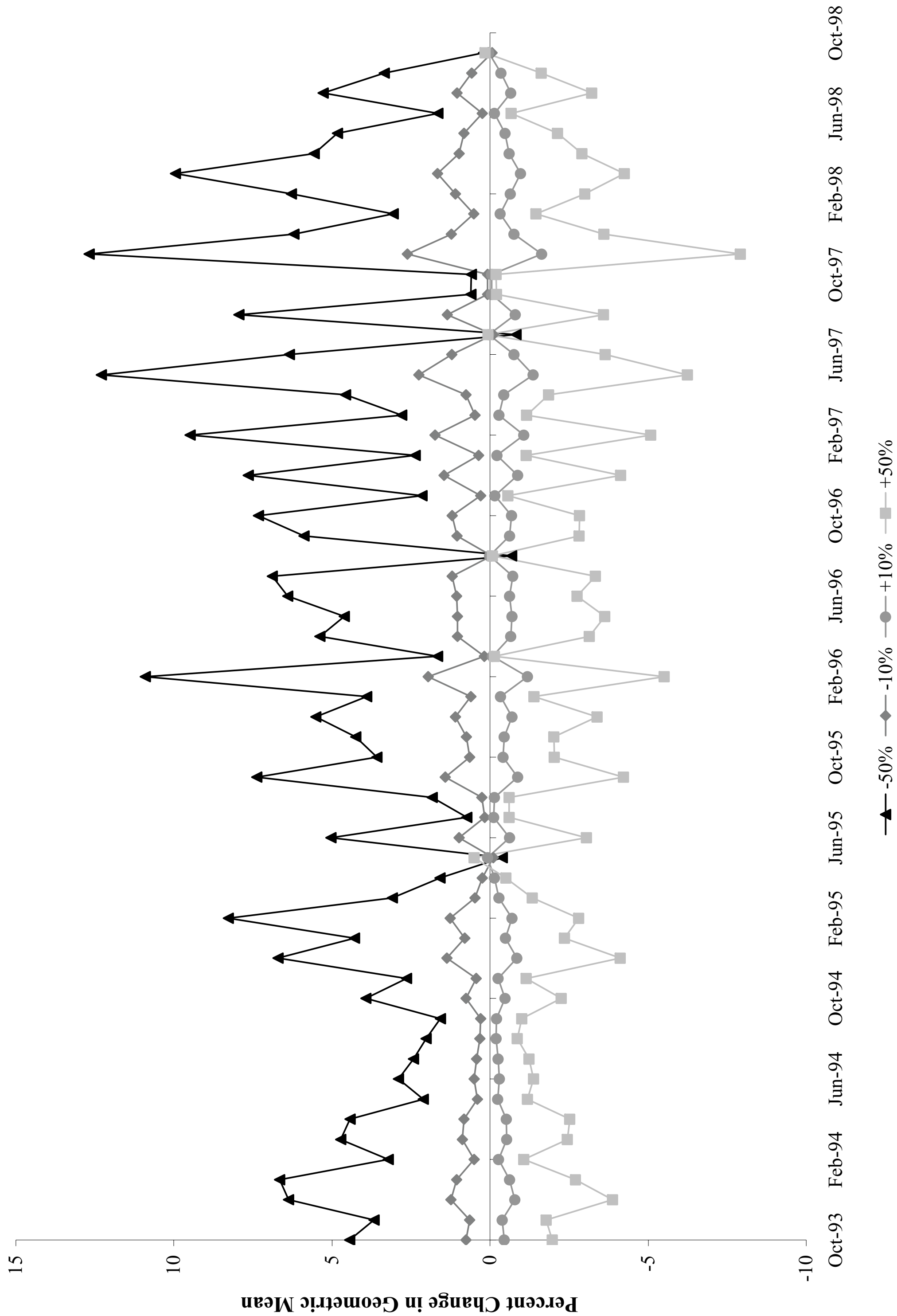

Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in the Knox Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).

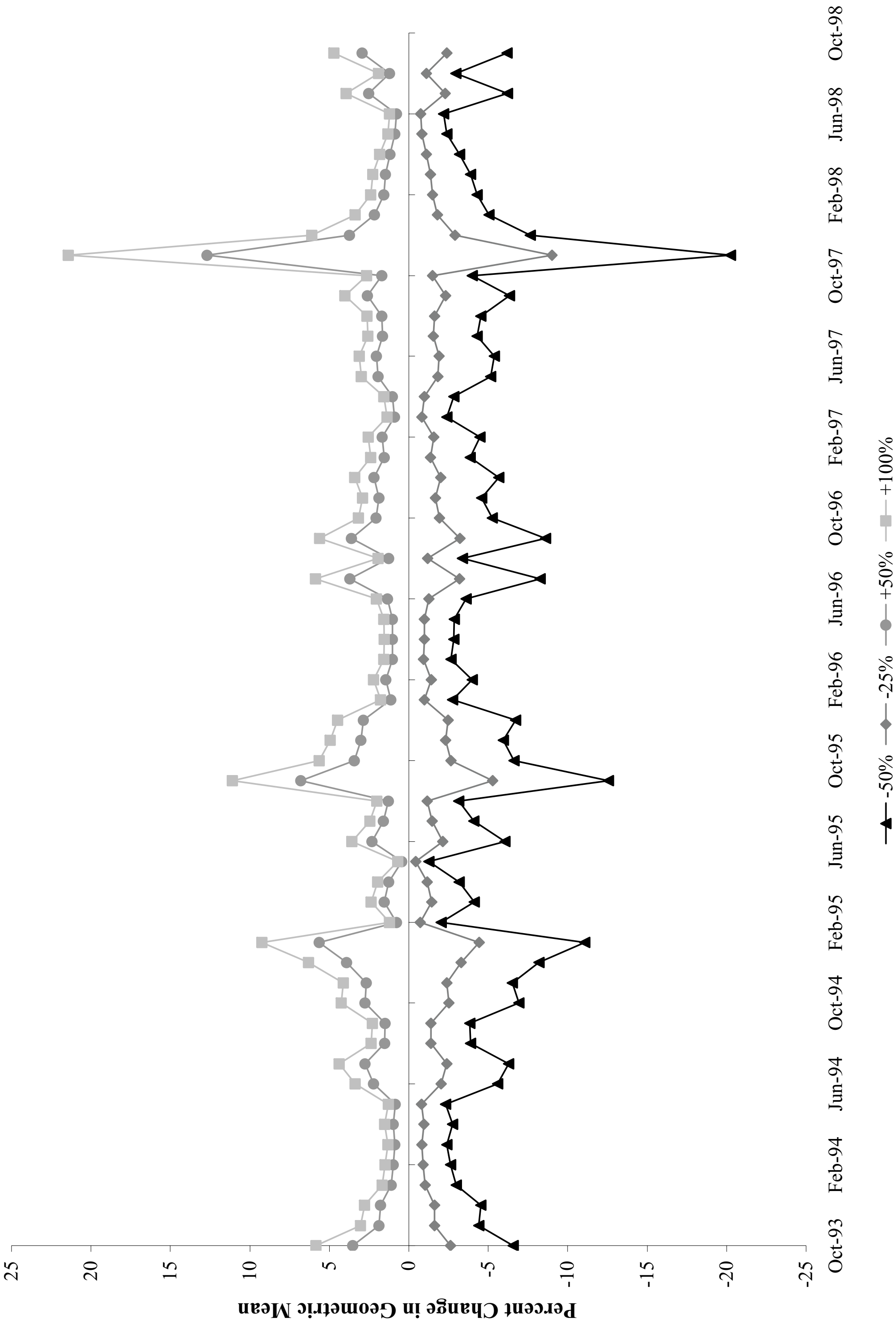

Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations in the Knox Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).

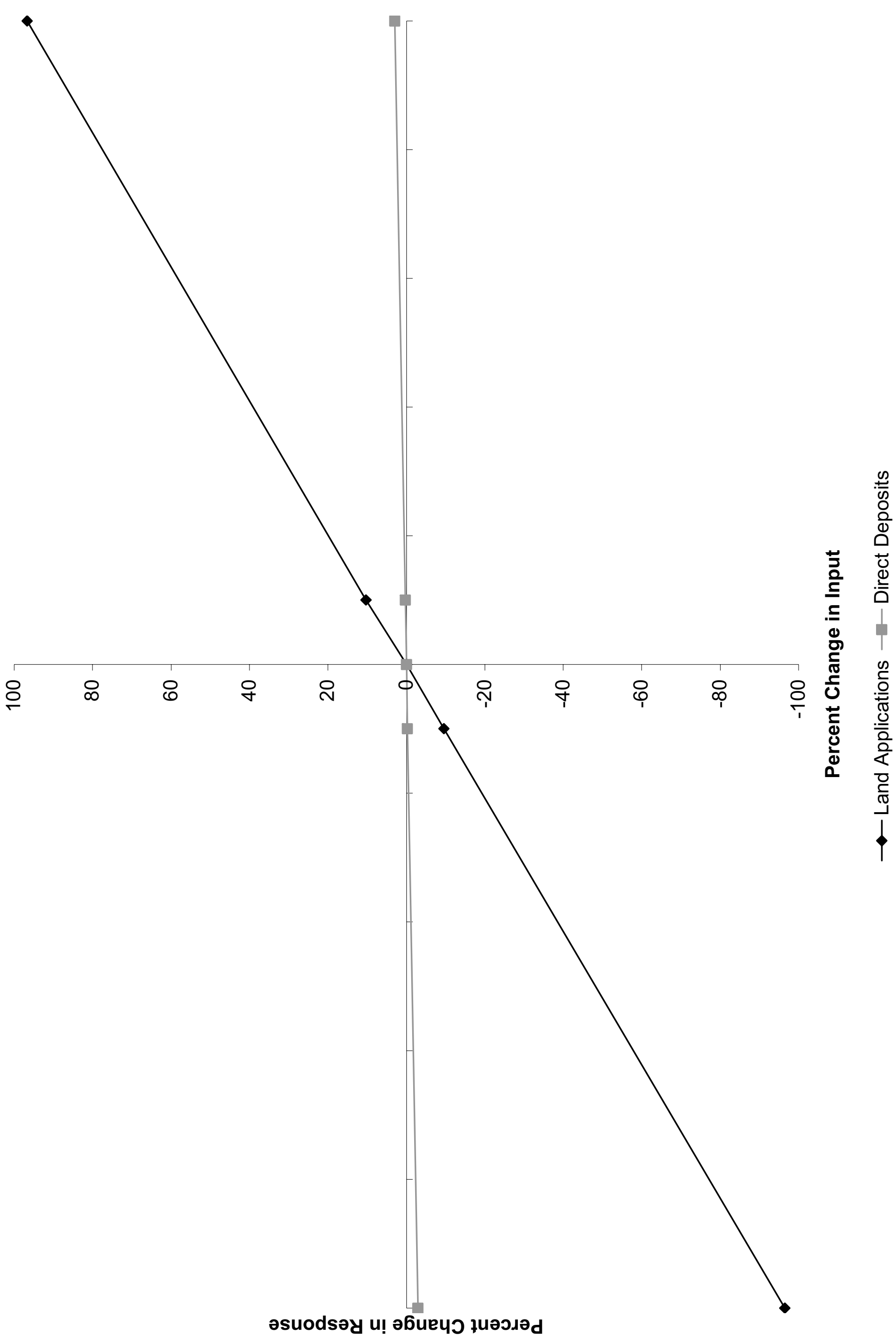

Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Knox Creek watershed.

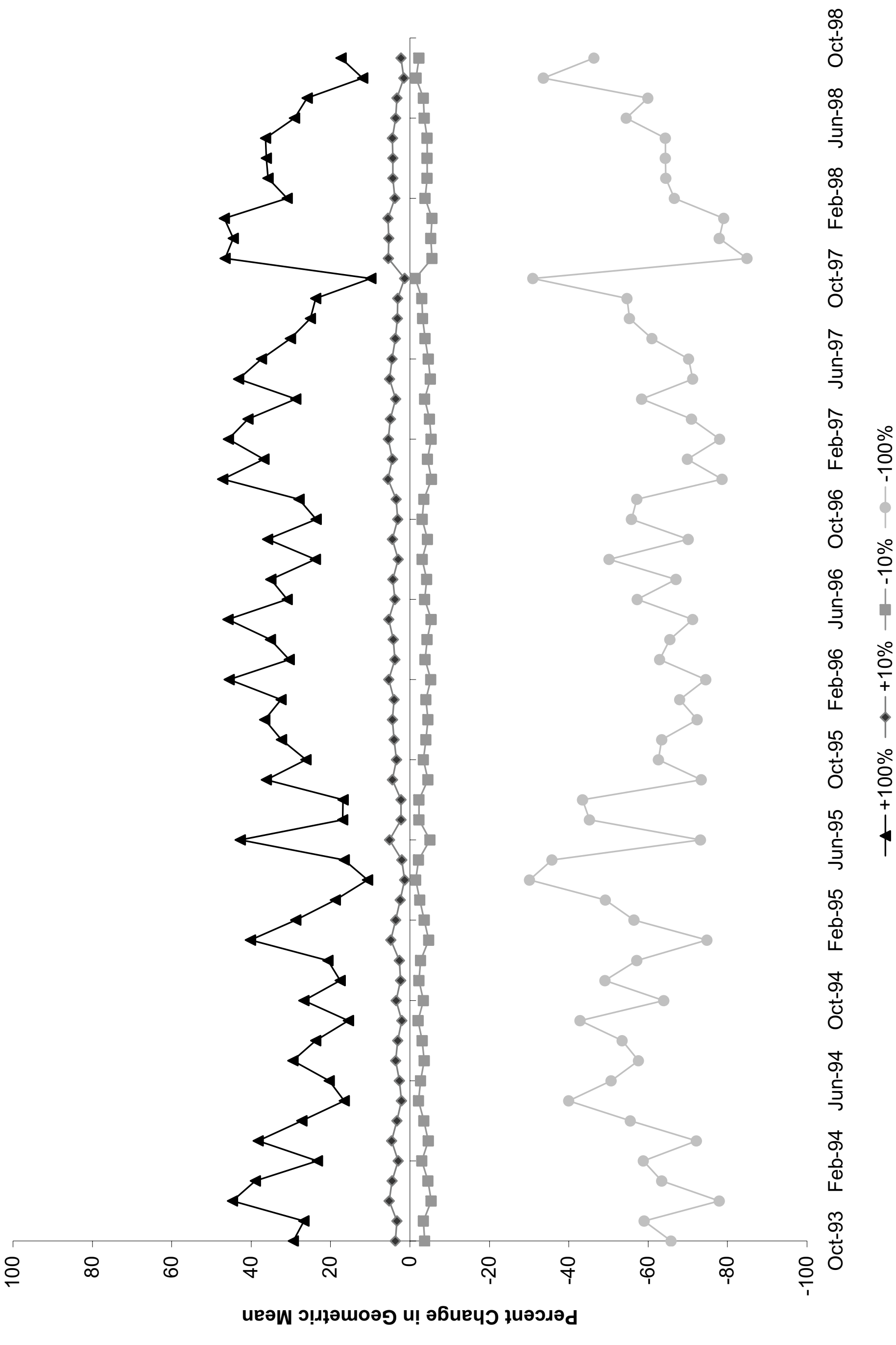

Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations in the Knox Creek watershed, as affected by changes in land-based loadings.

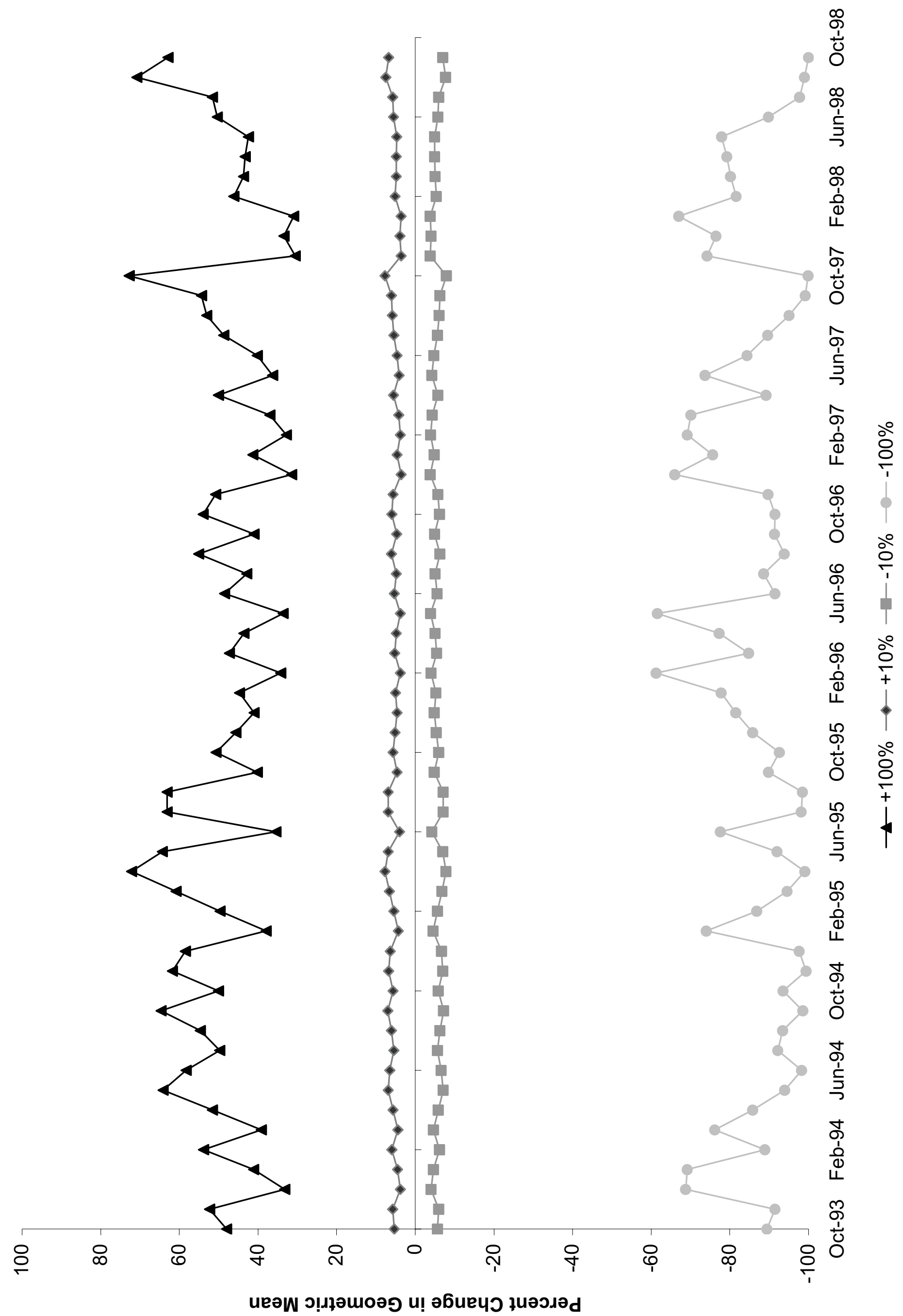

Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations in the Knox Creek watershed, as affected by changes in loadings from direct nonpoint sources.

4.7 Model Calibration Process

Calibration is performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based upon available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model.

4.7.1 Hydrologic Calibration

There is no continuous USGS stream flow station on Knox or Pawpaw Creek that was operational during the modeling time period. The DMME requires stream flow monitoring at sites in the watershed for compliance with mining permits. These stations are called monitoring point identification (MPID) sites. It is common to discover that the stream flow data from these MPID stations is not accurate. Most, if not all, of the flow values at MPIDs are baseflow. These values are instantaneous estimations of the stream flow; therefore, the data does not give a good representation of the creeks over time.

Due to the lack of continuous stream flow data for Knox and Pawpaw Creeks and low confidence in the accuracy of the MPID flow data, the paired watershed approach was used with additional refinement using instantaneous flow measurements at DMME MPID stations. Through this approach, an HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow data is available. The changes between the initial estimated and final calibrated parameters from the paired watershed model (*e.g.*, lower zone storage) are noted. Then the estimated parameters in the impaired watershed HSPF model are changed by the same percentages. In the case of the Knox Creek watershed, this representation was then refined through calibration to MPID instantaneous flow measurements collected primarily during base-flow conditions.

There are many factors to consider when finding a best-fit paired watershed. Drainage area, shape, proximity to the impaired watershed, land use, hydrologic soil group (HSG), and slope are among the most important. Three watersheds were compared to choose the best fit to the Knox Creek watershed: Levisa Fork (Buchanan County), the North Fork Powell River (Lee County), and the Upper Powell River (Wise County). Although the Levisa Fork watershed matches the Knox Creek watershed well regarding the parameters, it is considerably larger. Chapter 7 of Watershed Hydrology by P.E. Black (1991) gives a good discussion of the relationship between hydrology and watershed size and shape. Black states that size of the watershed affects peak flows considerably. Larger watersheds tend to have a lower rate of runoff per unit area during a peak flow event. This means the peak may be lower and later in time for a larger watershed, while a smaller watershed may be "flashy" where high flows are higher and low flows are lower than a large watershed. The Upper Powell River and North Fork Powell River watersheds are much closer to the Knox Creek watershed in area. The shape of a watershed effects the time of concentration of a watershed, which effects a stream's behavior to storm events (Black, 1991). The Upper Powell River watershed was chosen over the North Fork Powell River watershed because its shape is more similar to the Knox watershed. The hydrologic comparison of the watersheds was established by examining the land use distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group.

The first action taken to implement the paired watershed was to examine the similarities between the Upper Powell River and Knox Creek watersheds. The land use distributions are shown in Table 4.10. The four land use categories used were agricultural, urban, mining and natural. The mining land use category included active mining areas, abandoned mine land, reclaimed mining areas, and barren land; these accounted for 26% of the Upper Powell River watershed and 6% of the Knox Creek watershed.

Table 4.10 Land use distribution for Knox Creek and Upper Powell River watersheds.

Land use Categories	Land use	Knox Creek		Upper Powell River	
		acres	%	acres	%
Agricultural	Cropland/Row Crops	432	0.77	78	0.11
	Livestock Access	16	0.03	62	0.09
	Pasture	155	0.28	496	0.69
Total Agricultural		***604***	***1.08***	***636***	***0.88***
Urban	Residential	54	0.10	673	0.94
	Roads – Salt applied	191	0.34	42	0.06
	Roads – Brine applied	0	0	66	0.09
	Commercial	0	0	375	0.52
Total Urban		***245***	***0.44***	***1156***	***1.61***
Mining	Active	1,158	2.06	14,055	19.55
	Abandoned Mine Land	2,123	3.78	349*	0.49
	Reclaimed	429	0.76	1,551	2.16
	Barren	0	0	2,997	4.17
Total Mining		***3,710***	***6.61***	***18,952***	***26.36***
Natural	Forest	50,939	90.76	49,972	69.50
	Water	625	1.11	1,122	1.56
	Wetlands	0	0	65	0.09
Total Natural		***51,564***	***91.88***	***51,159***	***71.15***
Total		***56,123***	***100***	***71,903***	***100***

The hydrologic soil groups in both watersheds were examined. The soils series present in both the Upper Powell River and Knox Creek watersheds predominately consist of deep, well-drained soils. Both the paired watershed and TMDL watershed contain soils that were formed in regoliths (the layer of loose rock resting on bedrock, constituting the surface of most land) ranging from neutral to acidic, which consist mainly of weathered fine earth and bedrock fragments. These soils (specifically, the Bethesda, Fairpoint, Cedar Creek, and Kaymine soil series) were formed in regolith from surface mine operations. The latter two soil series were formed from the surface mining of coal. Based on the hydrologic soil group classification, the soil series present in the two watersheds predominantly range from "B" to "C" (Table 4.11). °

Table 4.11 Soil distribution in the Upper Powell River and Knox Creek watersheds.

Statsgo ID	Hydrologic Soil Group	Percent of Watershed	
		Upper Powell River	Knox Creek
VA003	B	1 %	0 %
VA016	B/C	0 %	5%
VA055	B	14 %	0 %
VA057	C	0 %	5%
VA078	B/C	85 %	84%
KY801	C	0 %	6%

Additional watershed characteristics of Upper Powell River and Knox Creek, including the drainage area, main channel slope, channel length, and the drainage density, were compared. The data, presented in Table 4.12 indicates that these physical characteristics of the watershed are similar.

Table 4.12 Comparison of the Upper Powell River watershed and Knox Creek watershed characteristics.

Watershed	Drainage Area (acre)	Main Channel Slope	Main Channel Length (ft)	Total Channel Length (ft)	Drainage Density (ft/acre)
Upper Powell River	71,905	0.06	111,052	1,444,722	20.09
Knox Creek	56,209	0.07	99,842	1,094,777	19.48

Based on the land use distribution, soil types, and the watersheds' physical characteristics, the Upper Powell River watershed is hydrologically similar to the Knox Creek watershed. An HSPF model was calibrated for the Upper Powell River watershed (VADEQ, 2003), where continuous flow data was available. The Upper Powell River model was calibrated for hydrologic accuracy using daily continuous stream flow data at USGS Station #03529500 on the Upper Powell River. Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZETP), the recession rates for groundwater (AGWRC), the amount of soil moisture storage in the upper zone (MON-UZSN) and lower zone (MON-LZSN), the infiltration capacity (INFILT), baseflow PET (potential evapotranspiration) (BASETP), direct ET from shallow groundwater (AGWETP), Manning's *n* for overland flow plane

(MON-MAN), and direct ET from shallow groundwater (AGWETP). Although HSPF is not a physically based model, and thus parameters are adjusted during calibration in order to match observed data, guidelines are provided by the EPA pertaining to typically encountered values.

The results of hydrology calibration for the Upper Powell River are presented in Table 4.13 and in Figures 4.12 through 4.14. Table 4.13 shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating a well-calibrated model. The distribution of flow volume in the final calibrated model between groundwater, interflow, and surface runoff at subwatershed 11 was 61%, 17%, and 20%, respectively.

Table 4.13 Hydrology calibration criteria and model performance for the Upper Powell River at USGS station #03529500 for the period 10/01/2001 through 9/30/2003.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	50.76	50.95	0.36%
Upper 10% Flow Values:	24.12	23.19	-3.87%
Lower 50% Flow Values:	6.93	7.59	9.56%
Winter Flow Volume	21.46	21.69	1.04%
Spring Flow Volume	17.67	16.38	-7.28%
Summer Flow Volume	4.15	4.49	8.07%
Fall Flow Volume	7.48	8.39	12.16%
Total Storm Volume	44.73	46.71	4.43%
Winter Storm Volume	19.97	20.64	3.33%
Spring Storm Volume	16.16	15.32	-5.19%
Summer Storm Volume	2.63	3.42	29.93%
Fall Storm Volume	5.96	7.33	22.97%

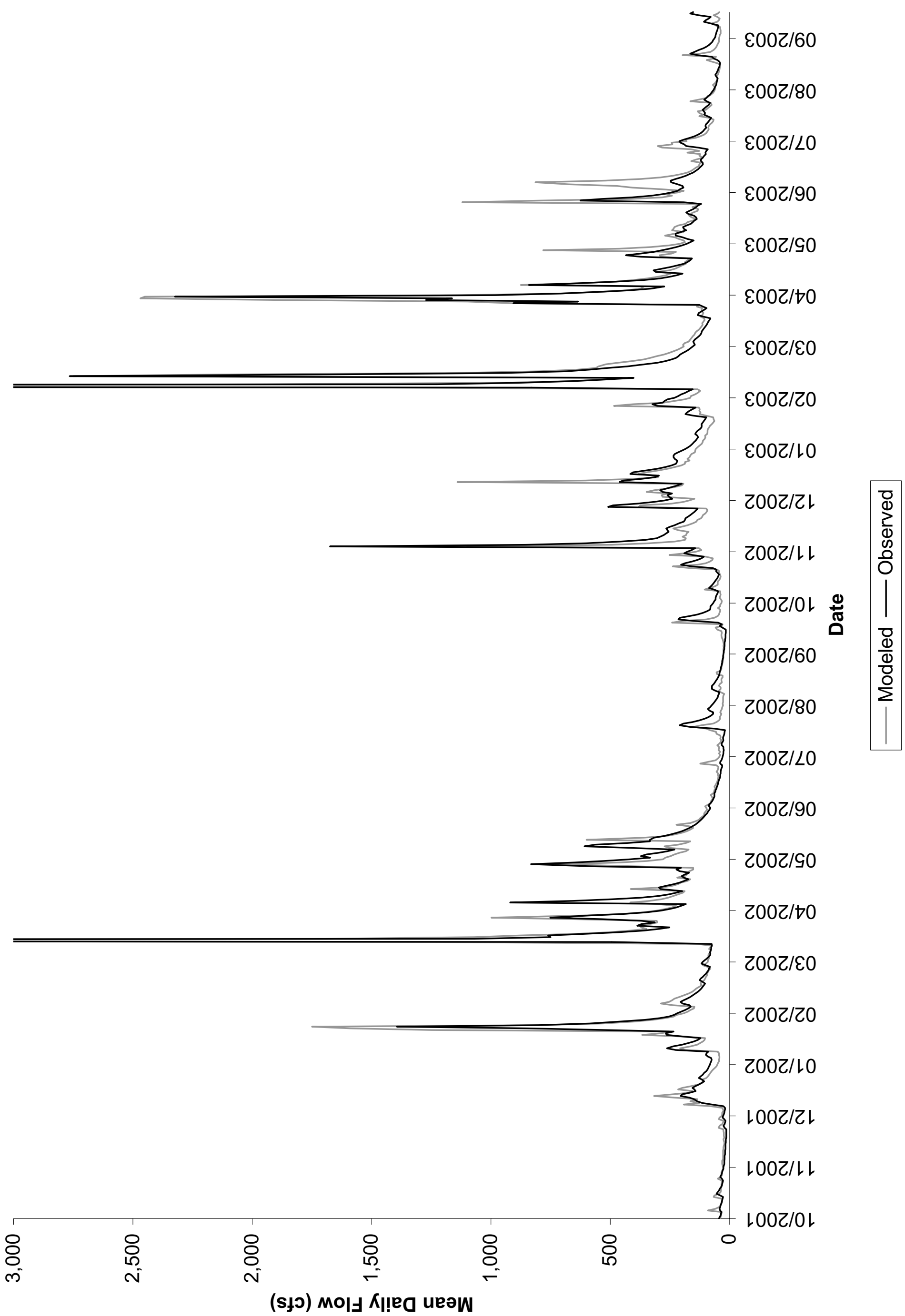

Figure 4.12 Hydrology calibration results for the Upper Powell River at USGS station #03529500 (10/01/2001 through 9/30/2003).

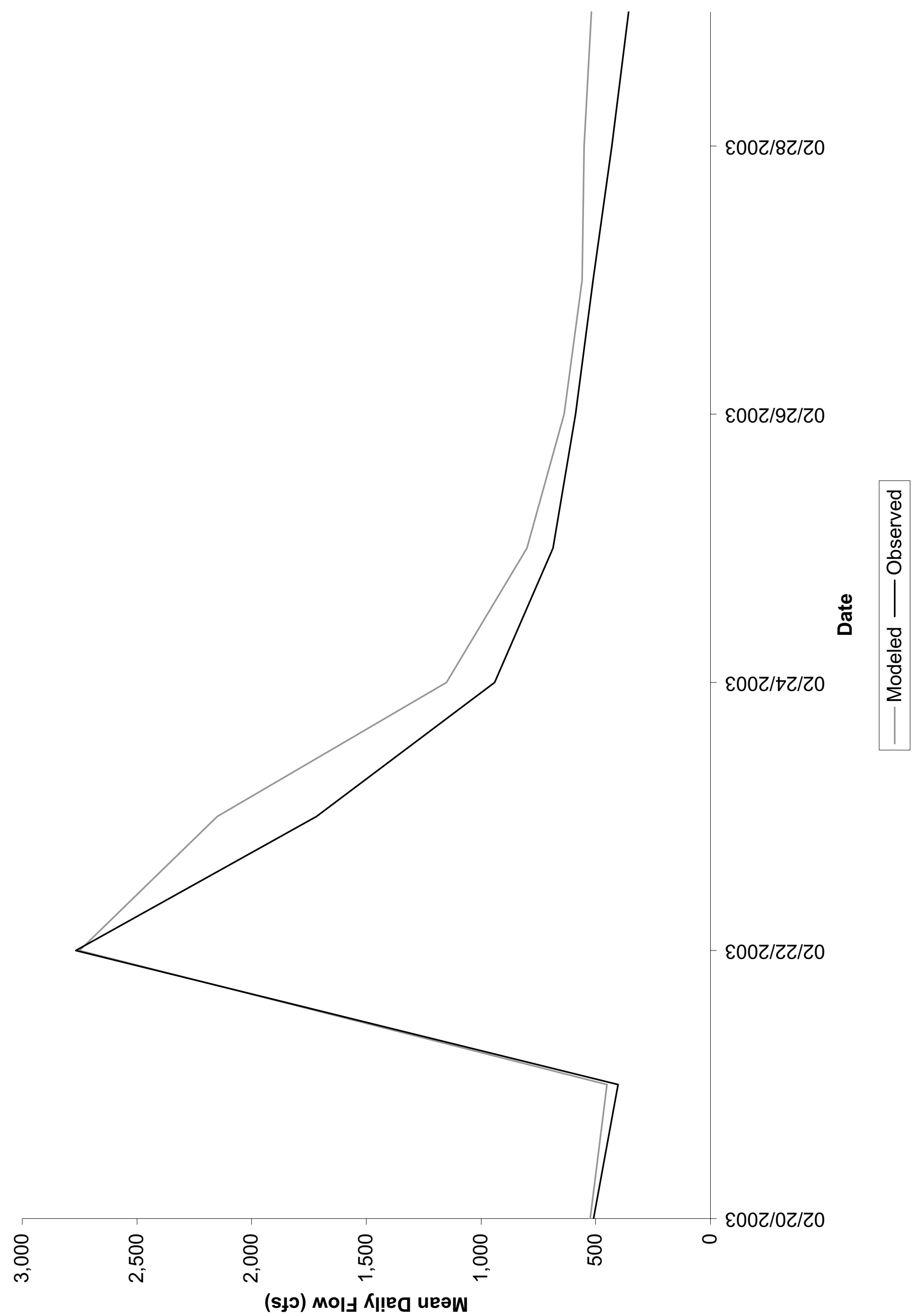

Figure 4.13 Hydrology calibration results for a single storm for the Upper Powell River at USGS station #03529500 (02/20/2003 – 03/01/2003).

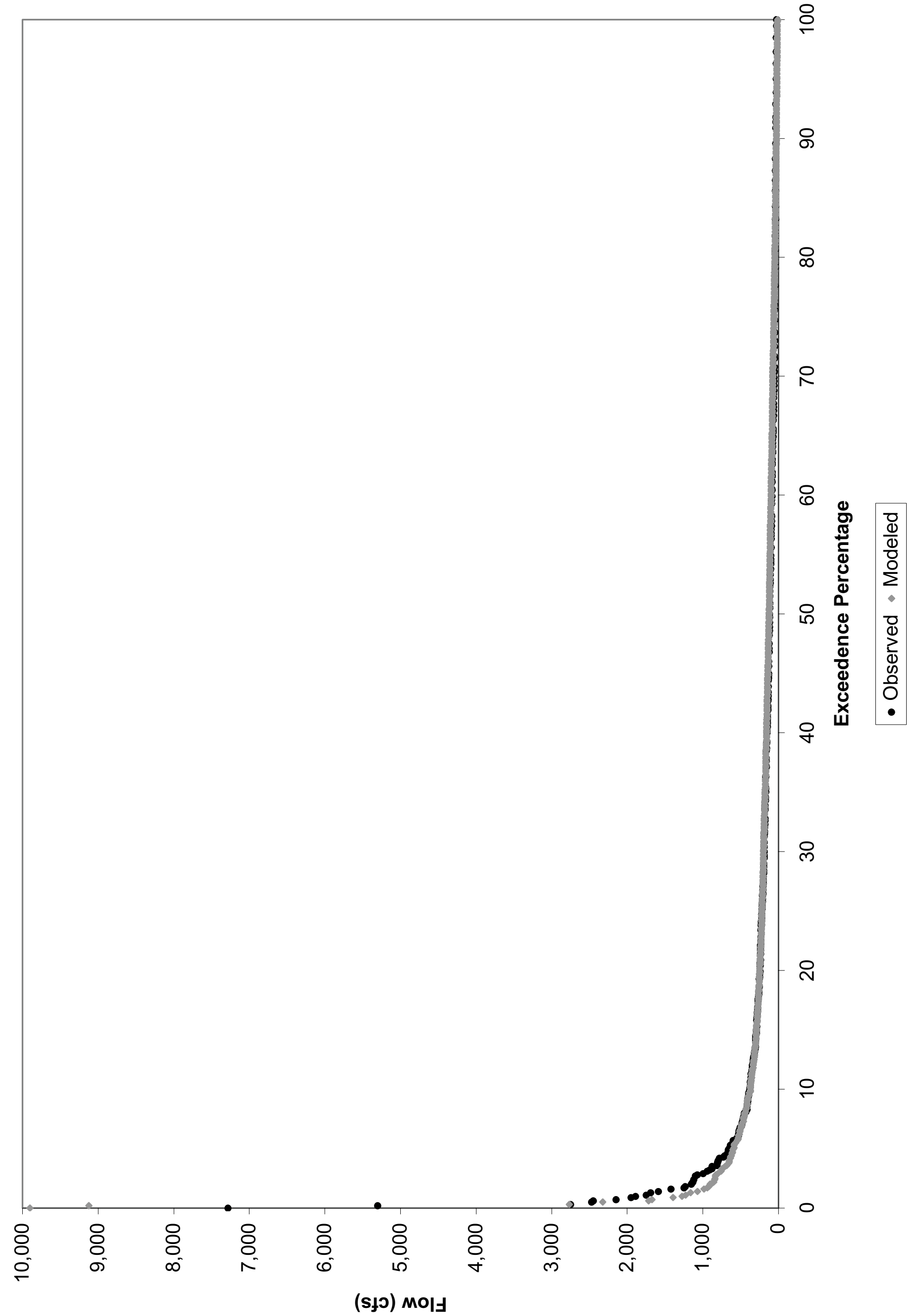

Figure 4.14 Upper Powell River flow duration at USGS station #03529500 (10/01/2001 through 9/30/2003).

The percent change between the initial and final calibrated HSPF parameters for the Upper Powell River watershed were used as the percent change in base parameters for the Knox Creek model. Then this model was further calibrated with stream flow values from MPIDs in the Knox Creek watershed. Table 4.14 contains the typical range for the above parameters along with the initial estimate and final calibrated value. Final calibrated parameters did not go outside of typical values, except in the case of SLSUR, which is an estimation of the slope of the overland flow path. This is a value calculated using GIS. It is not typically calibrated because it can be estimated with good confidence with digital elevation grids, and is a physically measurable value.

Table 4.14 Model parameters utilized for hydrologic calibration of the Knox Creek watershed and final calibrated values.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value (Adjusted to match observed data at MPID stations)
FOREST	---	0.0 – 0.95	1.0	1.0
LZSN	in	2.0 – 15.0	11.682 - 18.548	2.0 – 15.0
INFILT	in/hr	0.001 – 0.50	0.0688 - 0.1171	0.01 - 0.107
LSUR	ft	100 – 700	2 - 700	2 - 700
SLSUR	---	0.001 – 0.30	0.035 - 0.6664	0.035 - 0.6664
KVARY	1/in	0.0 – 5.0	0	0
AGWRC	1/day	0.85 – 0.999	0.978	0.978
PETMAX	deg F	32.0 – 48.0	40	40
PETMIN	deg F	30.0 – 40.0	35	35
INFEXP	---	1.0 – 3.0	2	2
INFILD	---	1.0 – 3.0	2	2
DEEPFR	---	0.0 – 0.50	0.417	0.417 – 0.5
BASETP	---	0.0 – 0.20	0.03	0.03
AGWETP	---	0.0 – 0.20	0	0
INTFW	---	1.0 – 10.0	1	1
IRC	1/day	0.30 – 0.85	0.7	0.7
MON-INT	in	0.01 - 0.40	0.01 - 0.31	0.01 – 0.31
MON-UZS	in	0.05 – 2.0	0.02 - 5.82	0.05 – 2.0
MON-MAN		0.05 – 0.50	0.05 - 0.15	0.05 - 0.15
MON-LZE	---	0.1 – 0.9	0.03 - 2	0.10 - 0.90
RETSC	in	0.01 – 0.30	0	0.1
KS	---	0.0 – 0.9	1.5	0.5

Flow data from six DMME MPIDs in the Knox Creek watershed were used to further refine the hydrologic calibration. The calibration results at subwatersheds 12 (MPID

6020049), 5 (MPID 6020016), 19 (MPID 6020043), 6 (MPID 6020042 and 6020087) the confluence of 4 and 16 (MPID 6020015) are shown in Figures 4.15 through 4.19.

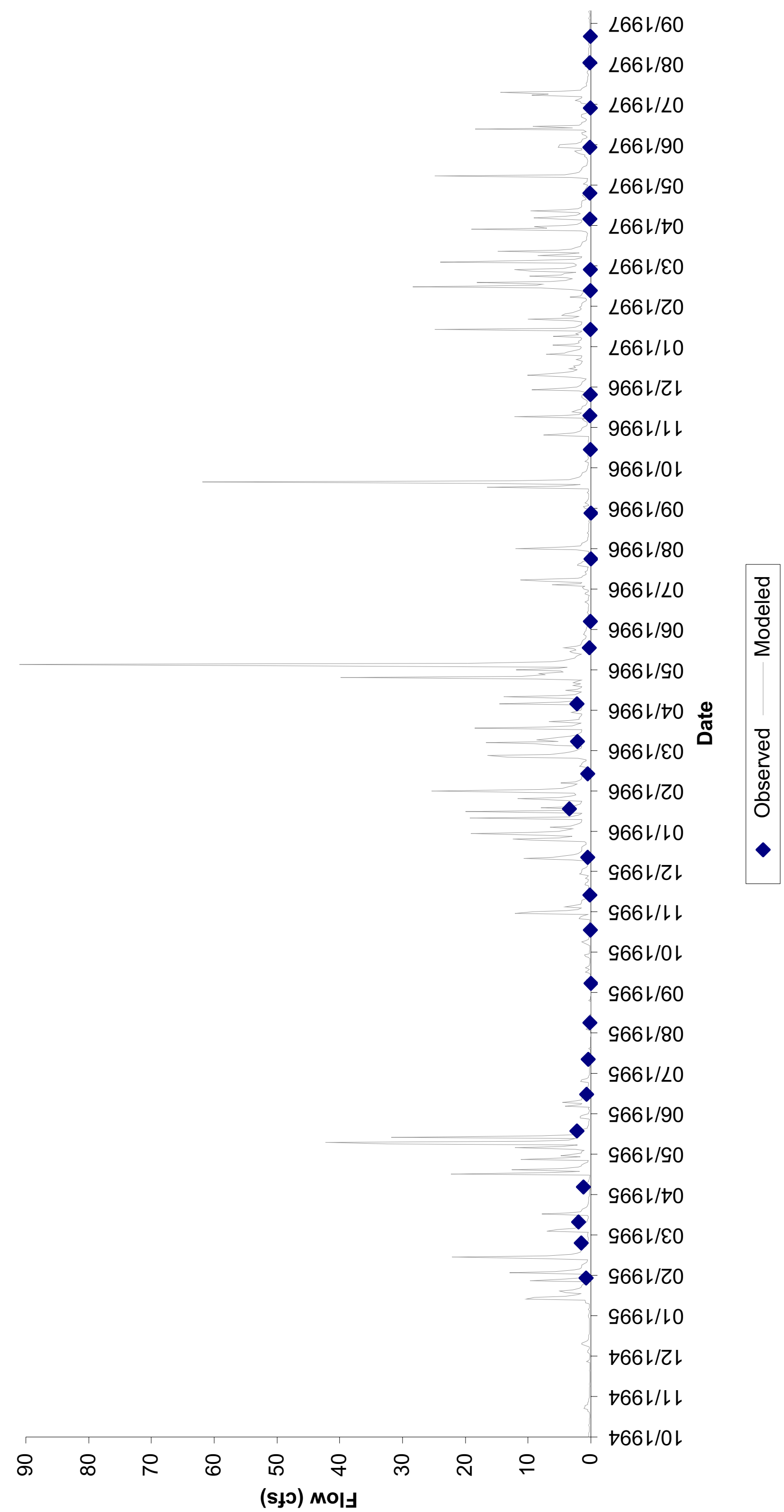

Figure 4.15 Hydrology calibration results for Knox Creek at the outlet of subwatershed 12 (MPID 6020015).

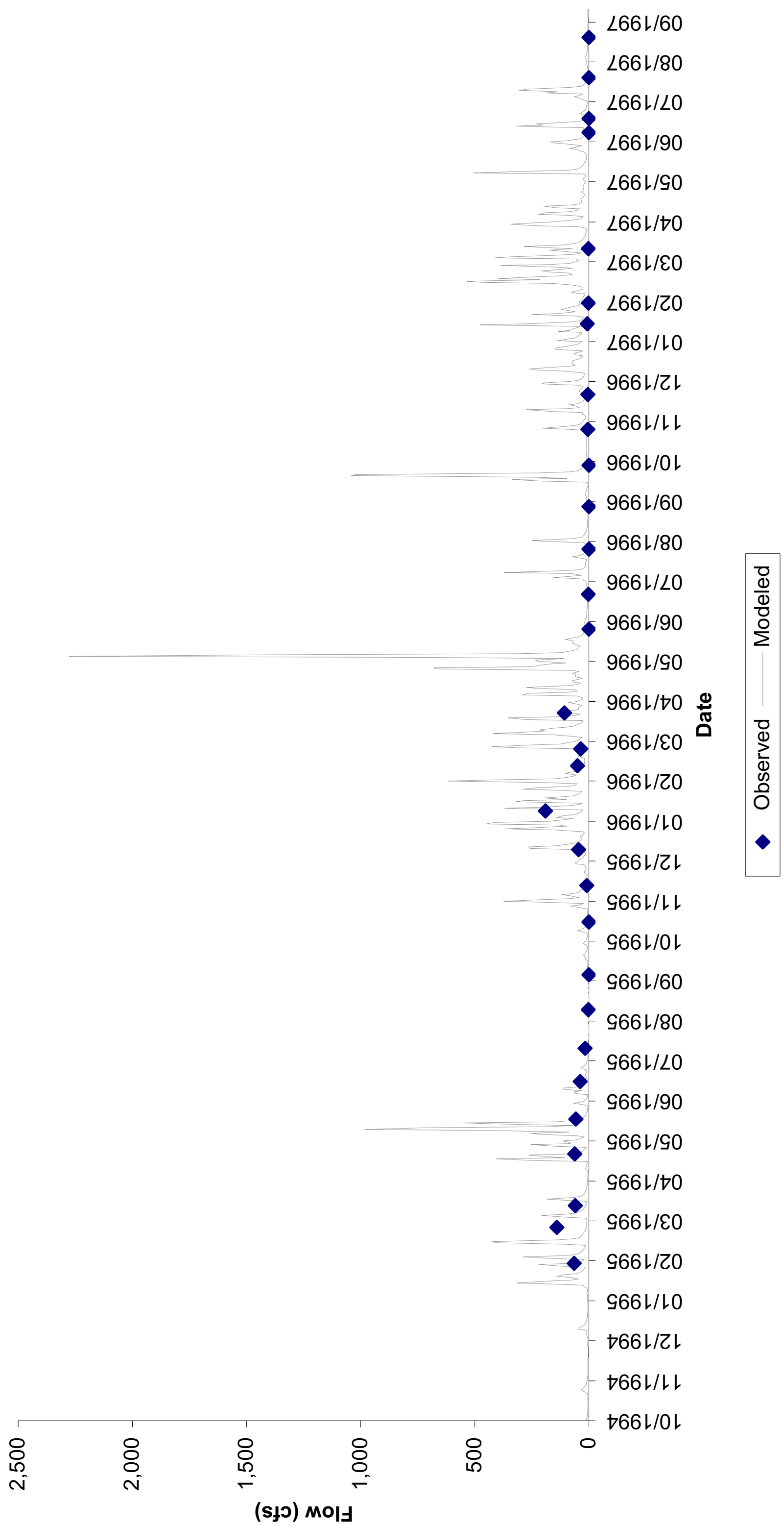

Figure 4.16 Hydrology calibration results for Knox Creek at the outlet of the confluence of subwatershed 4 and 16 (MPID 6020015).

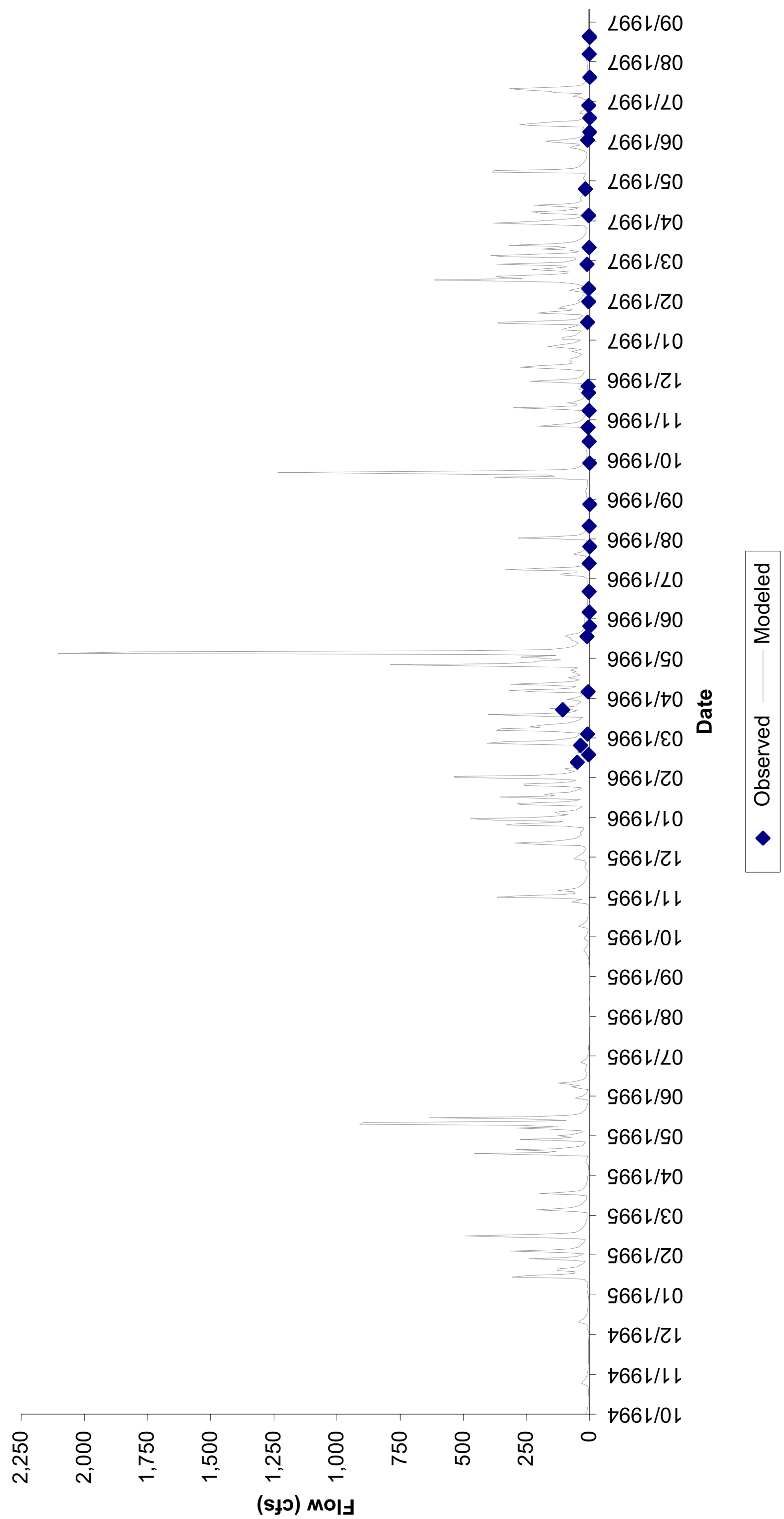

Figure 4.17 Hydrology calibration results for Knox Creek at the outlet of subwatershed 5 (MPID 6020016).

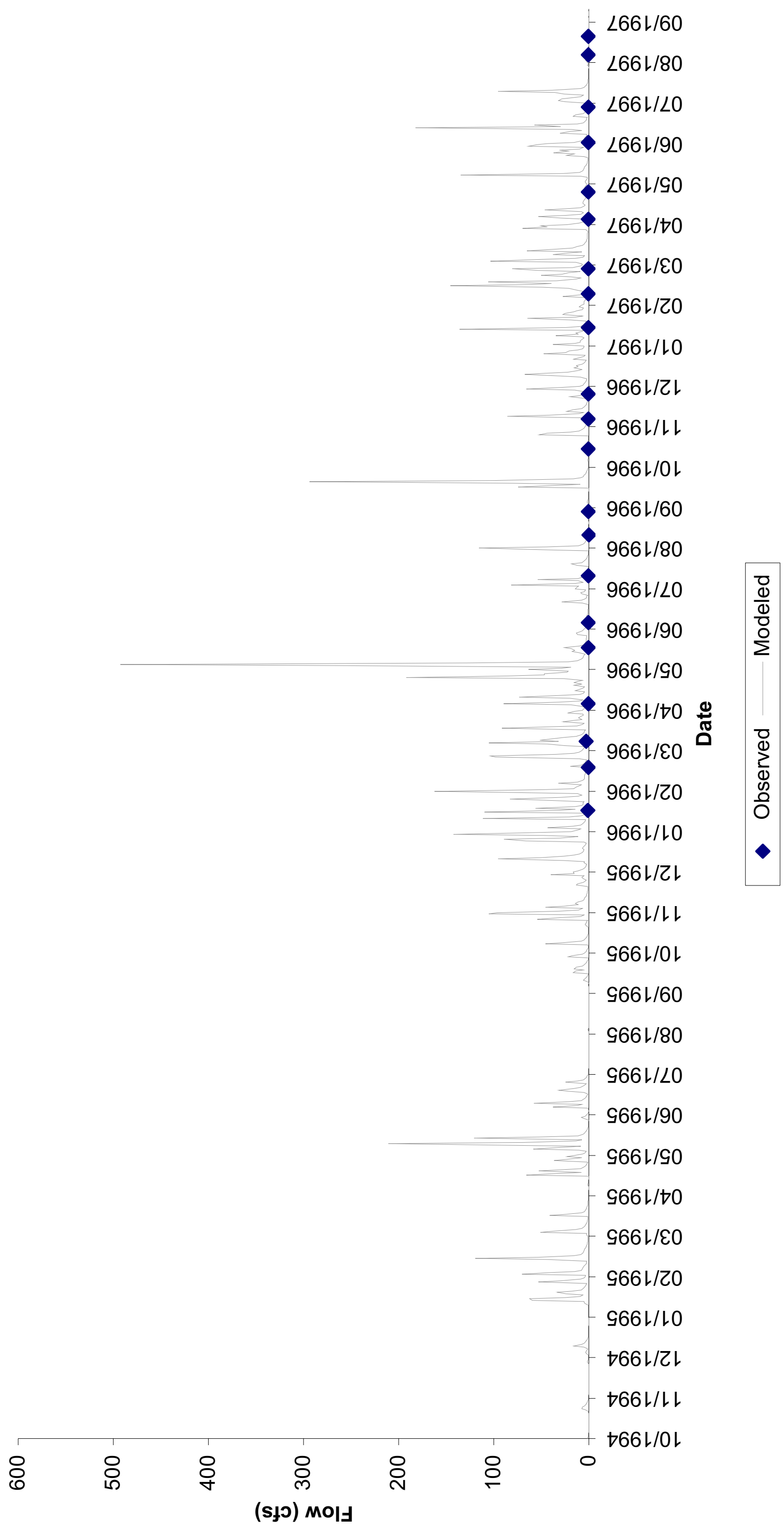

Figure 4.18 Hydrology calibration results for Knox Creek at the outlet of subwatershed 19 (MPID 6020043).

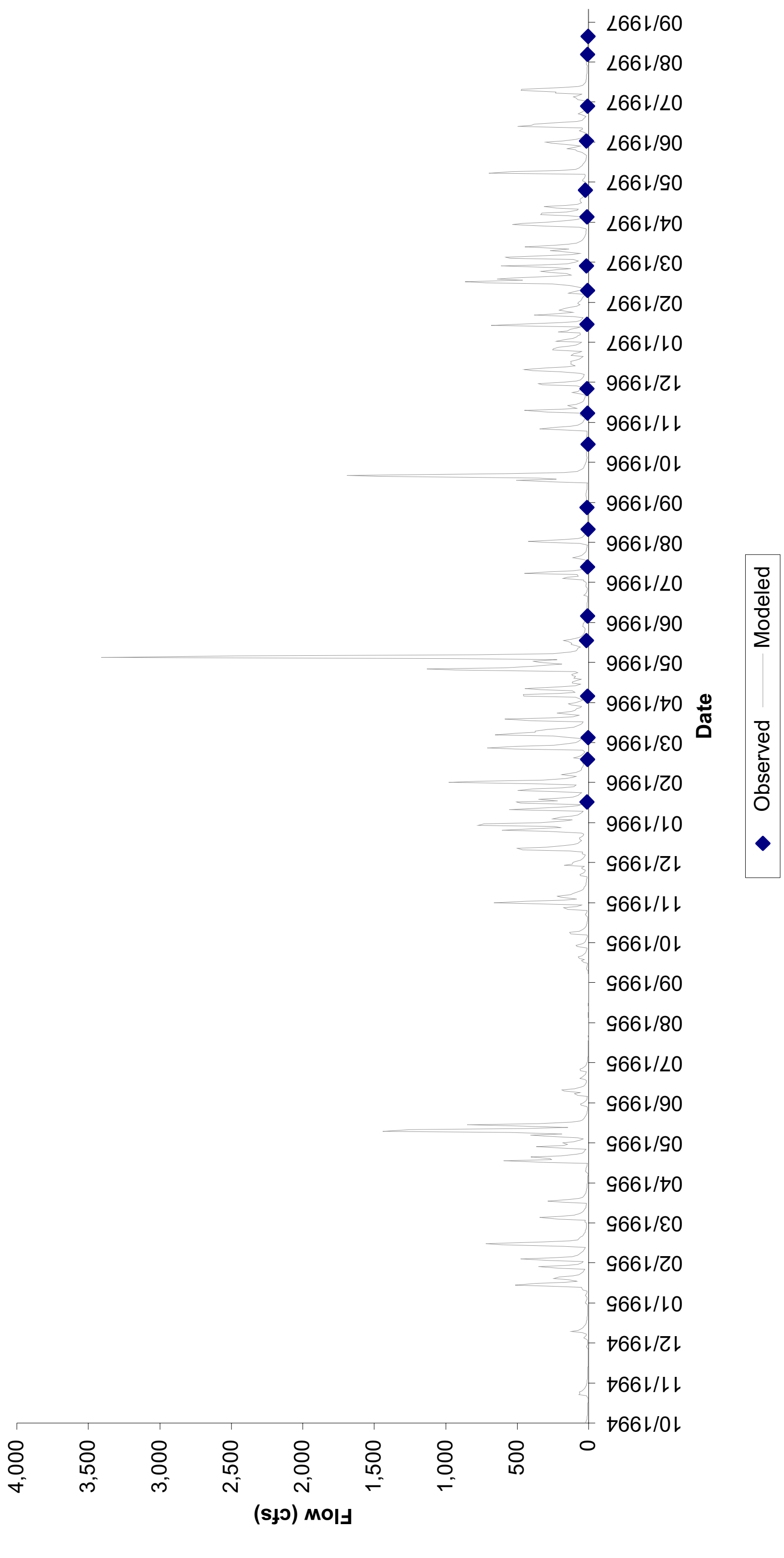

Figure 4.19 Hydrology calibration results for Knox Creek at the outlet of subwatershed 6 (MPID 6020042 and 6020087).

4.7.2 Water Quality Calibration

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (typically 8,000 or 16,000 cfu/100 mL) and low (typically under 100 cfu/100 mL) concentrations impede the calibration process.

Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established.

The Knox Creek fecal coliform water quality calibration was conducted using monitored data from 10/1/1993 to 9/30/1998. Table 4.15 and Figure 4.20 show the results of fecal coliform calibration for Knox Creek. All parameters used in the calibration were within typical ranges. Modeled fecal coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

Table 4.15 Model parameters utilized for fecal coliform water quality calibration of the Knox Creek watershed.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0 – 1.0E+20	0.0 – 6.8E+11	0.0 – 6.8E+11
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 6.8E+11	0.0 – 2.4E+13
WSQOP	in/hr	0.05 – 3.00	0.0 – 3.33	0.0 – 0.5
IOQC	FC/ft^3	0.0 – 1.0E+06	0.0	0.0
AOQC	FC/ft^3	0 – 10	0.0	0.0
DQAL	FC/100mL	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.0	1.00	0.79
THFST	---	1.0 – 2.0	1.07	1.07

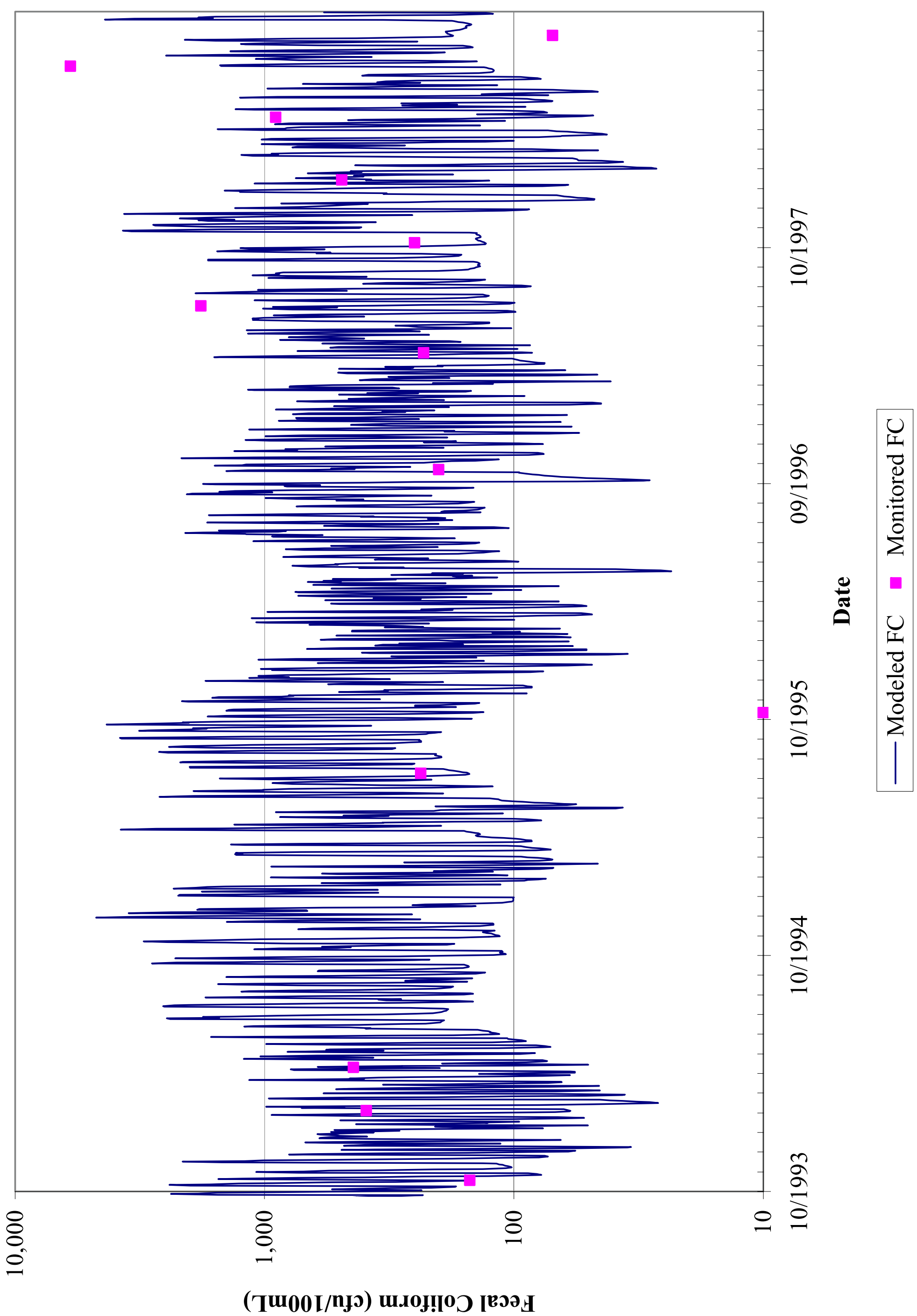

Figure 4.20 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in the Knox Creek impairment at subwatershed 7 during calibration.

4.7.2.1 Water Quality Calibration Statistics

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{\left(n-1\right)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values around an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data and found to be at reasonable levels (Table 4.16).

The standard error in the Knox Creek model is 100.5 (Table 4.16). This standard error value can be considered quite reasonable when one takes into account the value is calculated by using daily averages instead of the value simulated at each one-hour time step. The maximum hourly modeled fecal coliform value (5,364) was close to the maximum observed value (6,000) during the modeling time period.

Table 4.16 Mean standard error of the fecal coliform calibrated model for Knox Creek (10/1/93 through 9/30/98).

Subwatershed	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
7	6AKOX006.52	100.5	5,364	6,000

A comparison between the geometric mean of observed fecal coliform data and the modeled fecal coliform values is shown in Table 4.17. The differences between the percent exceedances of the instantaneous standard are also shown. These differences are within the standard deviation of the observed data at each station and, therefore, the fecal coliform calibration is acceptable. The column ‘n’ is the number of observations.

Table 4.17 Comparison of modeled and observed standard violations for the fecal coliform calibrated model for Knox Creek.

		Modeled Calibration Load Fecal Coliform 10/1/93 - 9/30/98			Monitored Fecal Coliform 10/1/93 - 9/30/98		
Subwatershed	Station ID	*n*	Geometric Mean (cfu/100ml)	Exceedances of Instantaneous Standard	*n*	Geometric Mean (cfu/100ml)	Exceedances of Instantaneous Standard
7	6AKOX006.52	1,826	318.47	38.17%	13	308.88	38.46%

4.8 Existing Loadings

All appropriate inputs were updated to 2005 conditions. All model runs were conducted using precipitation data during hydrologic calibration. Figure 4.21 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126-cfu/100mL standard for Knox Creek. Figure 4.22 shows the instantaneous values of *E. coli* concentrations in relation to the 235-cfu/100 mL standard for Knox Creek. These figures show that there are violations of both standards at the impairment outlet. Appendix B contains tables with monthly loadings to the different land use areas in each subwatershed.

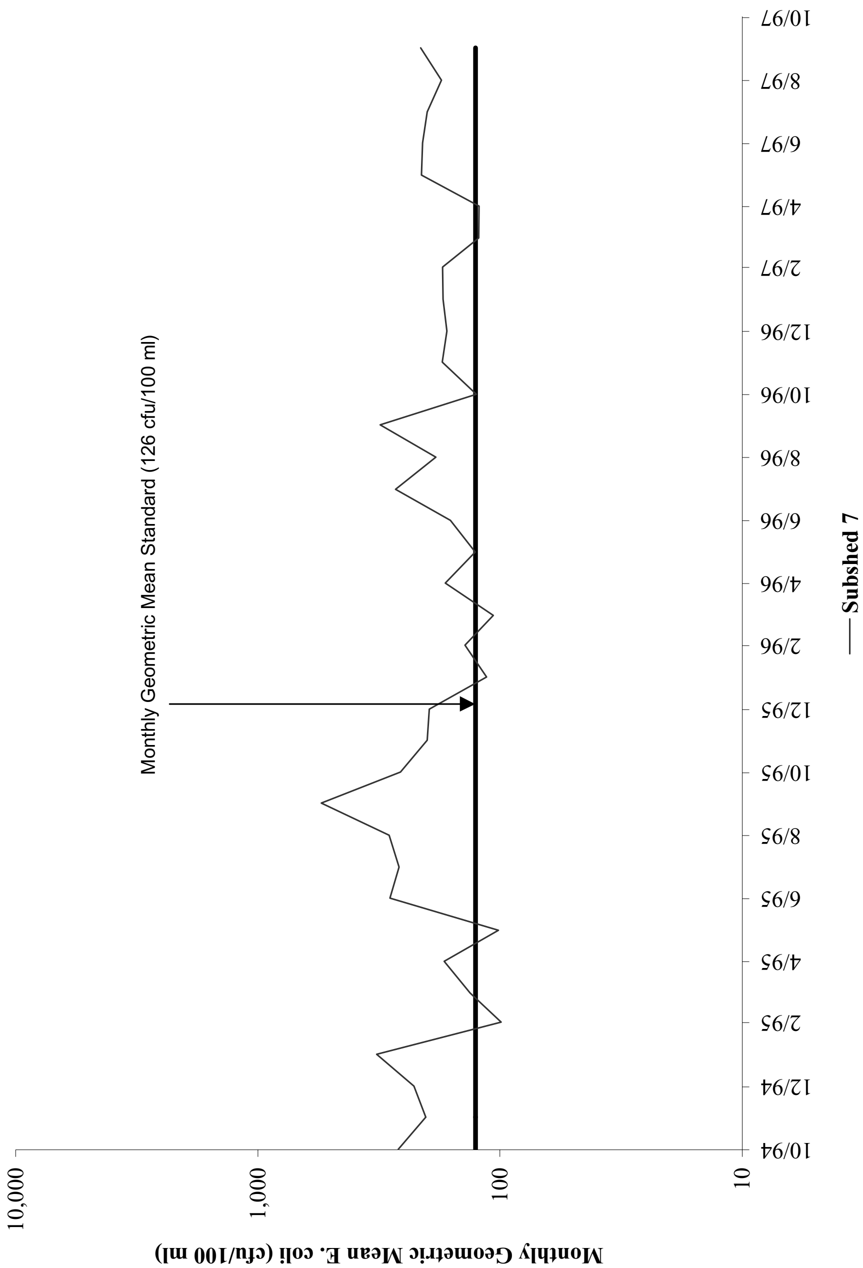

Figure 4.21 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Knox Creek impairment (subwatershed 7).

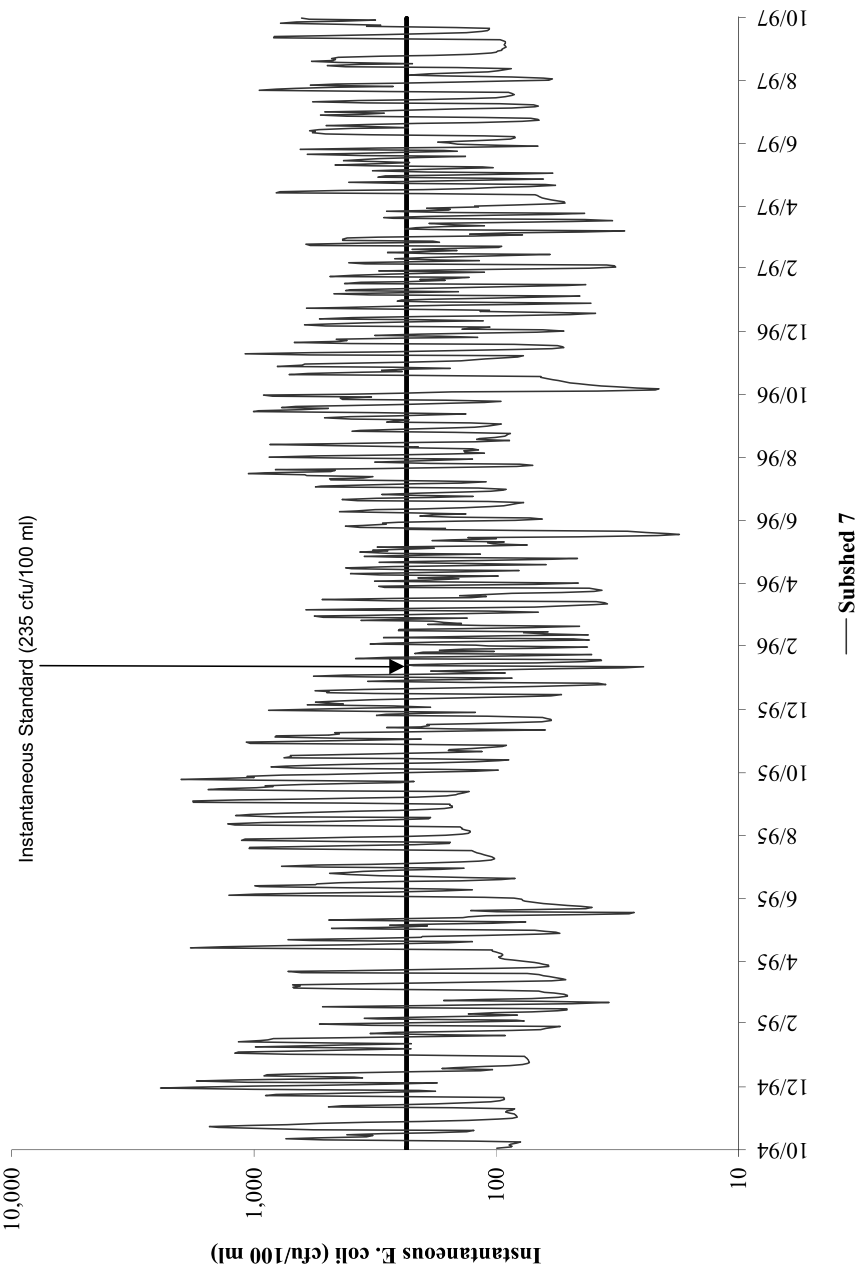

Figure 4.22 Existing conditions (*i.e.*, mean daily) of *E. coli* concentrations at the outlet of the Knox Creek impairment (subwatershed 7).

5. ALLOCATION

TMDLs consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint/non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.,* accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration).

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not under-estimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is insured that the recommended reductions will, in fact, succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standards were attained. The fecal bacteria TMDL developed for Knox

Creek was based on the Virginia State Standard for *E. coli*. As detailed in section 2.1, the *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 mL, and that a maximum single sample concentration of *E. coli* not exceed 235 cfu/100 mL. According to the guidelines put forth by VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a dataset containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

Where C_{ec} is the concentration of *E. coli* in cfu/100 mL, and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met. The development of the allocation scenario was an iterative process that required numerous runs with each run followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

There are nine non-mining point sources currently permitted to discharge in the Knox Creek watershed (Figure 3.2 and Table 3.2). Of these sources, six are permitted for fecal control. For allocation runs, sources without fecal control permits were modeled as discharging at the design flow, with no *E. coli*. The allocation for the sources permitted for fecal control is equivalent to its current permit level (*i.e.,* design flow and 126 cfu/100 mL).

5.2.2 Load Allocation

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.,* livestock, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. Bacterial source tracking (BST) during 2003-2004 sampling periods confirmed the presence of human, pet, livestock and wildlife contamination.

Model results indicate that human direct deposits (*i.e.,* straight pipes) and residential nonpoint sources (NPS) are significant in the watershed. This is in agreement with the results of BST analysis (Chapter 2). Allocation scenarios for Knox Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed. All reductions in the following scenarios were done to loads from the Virginia portion of the watershed only.

The first objective of the reduction scenarios was to explore the role of anthropogenic (human, pet, livestock) sources in standards violations. First, scenarios were explored to determine the feasibility of meeting standards without wildlife reductions. Following this theme, Scenario 2 had a 100% reduction in uncontrolled direct residential discharges (*i.e.,* straight pipes). A decrease in the violations was observed, but the standards were not met. Scenario 3 had a 90% reduction in direct livestock deposition, and 50% reductions to NPS loads from residential and agricultural lands, as well as a 100% reduction of straight pipes. This scenario showed improvement, but the standards were still not met. Scenario 4 shows 100% reductions to all anthropogenic sources; however, exceedances still persisted. This scenario shows that reductions to wildlife loads must be made.

Scenario 5 shows that even with 99% reductions on all land-based loads the instantaneous standard is not met. A 99.5% reduction of agricultural and residential land-based loads allows the stream to meet both standards (Scenario 6). Additional scenarios were made by iteratively reducing nonpoint source wildlife loads and direct wildlife loads evenly until a scenario was found that resulted in zero exceedances of both standards. Scenario 7 shows that a 94% reduction in direct wildlife loads and land-based loads on forest lands met both standards. Scenario 8 shows that the reduction from direct wildlife loads can be reduced to 87%; however the land-based loads from natural areas (forest, wetlands, etc) cannot be reduced further (Scenario 9).

Next, the scenario with the least reductions was found by decreasing the reduction of direct livestock loads while maintaining zero percent violations of both standards (Scenario 10). The TMDL goal is 89% reduction in fecal bacteria from direct livestock, 99.5% reduction from NPS agricultural loads, 99.5% from NPS residential loads, 100% reduction of direct human loads, 87% reduction from direct wildlife loads, and a 94% reduction from NPS forest/wetland loads.

Scenario 11 is the Stage 1 goal. This scenario gives reductions of anthropogenic sources, which yields instantaneous standard violations near 10%. This goal is 89% reduction in fecal bacteria from direct livestock, 98% reduction from NPS agricultural and residential loads, and 100% reduction of direct human loads. The final TMDL reduction scenario requires no reduction to Kentucky bacteria loads.

Table 5.1 Bacteria reduction scenarios for Knox Creek.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 126 cfu/100ml	Single Sample > 235 cfu/100ml
1	0	0	0	0	0	0	91.67	47.81
2	0	0	0	0	100	0	80.56	41.41
3	0	0	90	50	100	50	58.33	31.17
4	0	0	100	100	100	100	19.44	8.50
5	99	99	100	99	100	99	0.00	0.27
6	99	99	100	99.5	100	99.5	0.00	0.00
7	94	94	100	99.5	100	99.5	0.00	0.00
8	87	94	100	99.5	100	99.5	0.00	0.00
9	87	93	100	99.5	100	99.5	0.00	0.09
10	87	94	89	99.5	100	99.5	0.00	0.00
11	0	0	89	98	100	98	25.00	9.51

5.2.2.1 Final bacteria TMDL for Knox Creek

In the Knox Creek watershed, subwatershed 4 was the limiting subwatershed; it required the strictest reductions to allocate. Figure 5.1 shows graphically the existing and allocated conditions for the geometric-mean concentrations in Knox Creek at subwatershed 4. Figure 5.2 shows the existing and allocated conditions of the instantaneous *E. coli* concentration in Knox Creek at subwatershed 4.

Table 5.2 indicates the land-based and direct load reductions resulting from the final allocation. Table 5.3 shows the final fecal bacteria TMDL loads for the Knox Creek impairment.

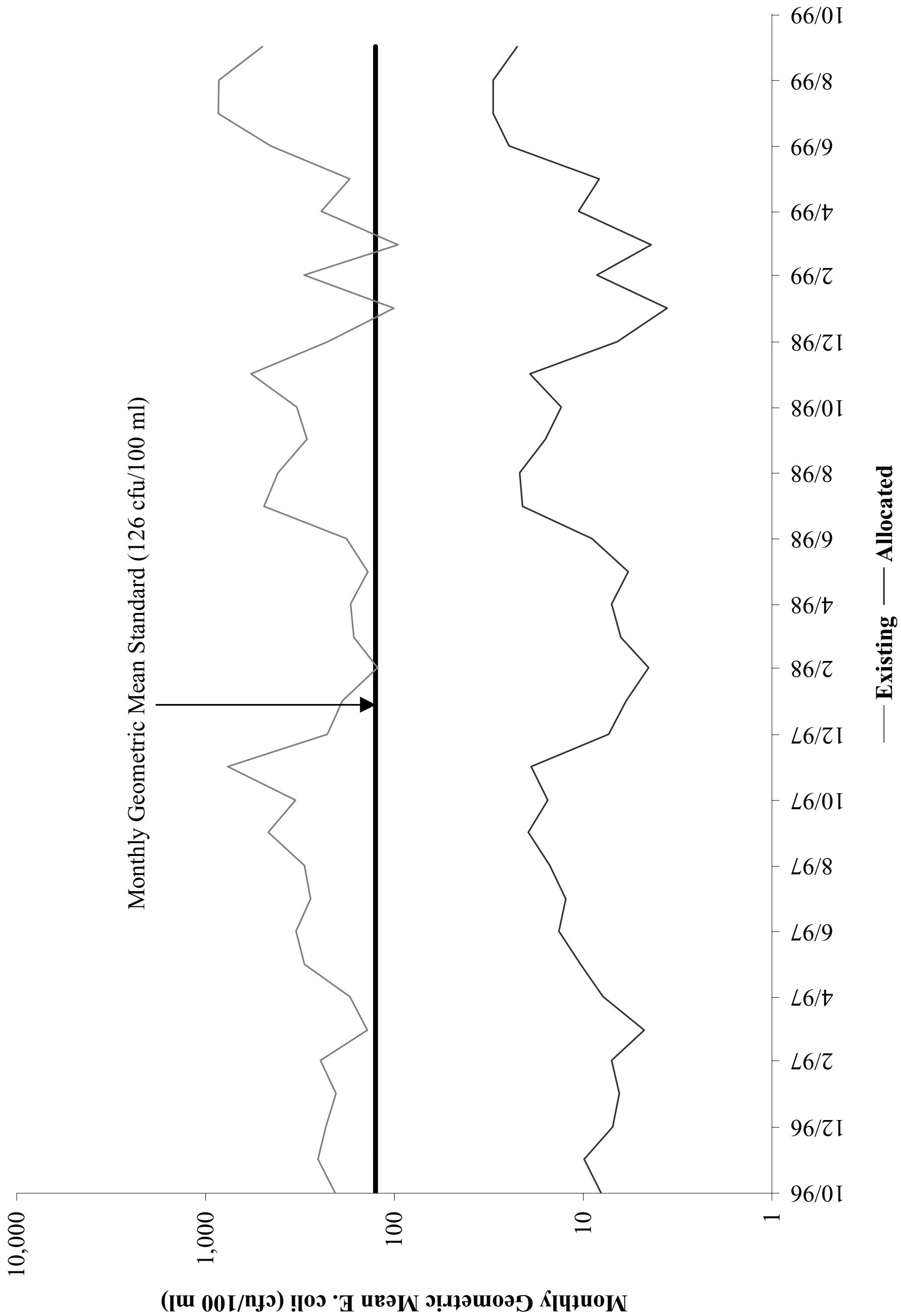

Figure 5.1 Monthly geometric mean *E. coli* concentrations for Knox Creek at subwatershed 4 under existing and allocated conditions.

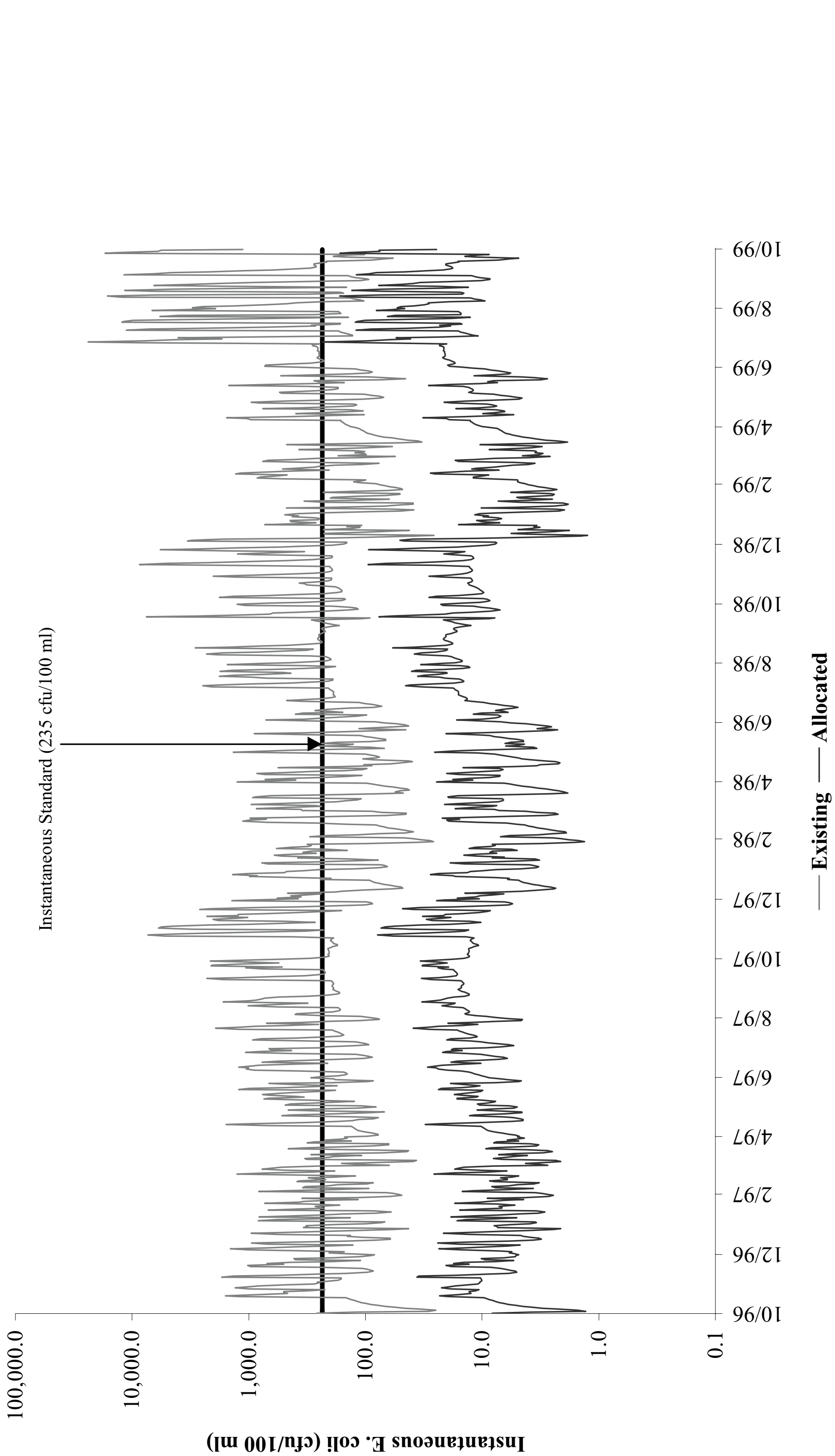

Figure 5.2 Instantaneous *E. coli* concentrations for Knox Creek at subwatershed 4 under existing and allocated conditions.

Table 5.2 Fecal coliform land-based loads deposited on all land uses and direct loads in the Knox Creek watershed for existing conditions and for the final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based[1]			
Active	7.71E+12	4.63E+11	94
AML	9.54E+12	5.72E+11	94
Cropland	1.09E+13	5.45E+10	99.5
Forest	3.94E+14	2.36E+13	94
LAX	3.72E+12	1.86E+10	99.5
Pasture	1.15E+14	5.75E+11	99.5
Reclaimed	3.34E+12	2.00E+11	94
Residential	1.14E+15	5.70E+12	99.5
Salted_Roads	8.63E+12	5.18E+11	94
KYActive	1.37E+12	1.37E+12	0
KYAML	1.34E+11	1.34E+11	0
KYCropland	1.30E+09	1.30E+09	0
KYForest	3.61E+13	3.61E+13	0
KYPasture	2.47E+10	2.47E+10	0
KYReclaimed	2.98E+11	2.98E+11	0
KYSalted_Roads	2.76E+09	2.76E+09	0
KYWater	4.74E+12	4.74E+12	0
Direct			
Human - VA	1.63E+13	0.00E+00	100
Human - KY	9.85E+11	9.85E+11	0
Wildlife - VA	2.22E+13	2.88E+12	87
Wildlife - KY	9.70E+11	9.70E+11	0
Livestock - VA	2.87E+11	3.15E+10	89

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after allocation in the Knox Creek watershed at the outlet.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Knox Creek	4.53E+10	1.74E+13	Implicit	1.75E+13
VA0026972	*1.39E+10*			
VA0067521	*2.96E+10*			
VAG400180	*8.71E+08*			
VAG400391	*8.71E+08*			

To determine a future allocation scenario, the same final allocation scenario was evaluated with an increase in permitted loads. The permitted loads were increased by a factor of five to simulate population growth. The TMDL table that reflects this future scenario is in Appendix C.

PART III: GENERAL STANDARD (BENTHIC) TMDLS

6. WATER QUALITY ASSESSMENT

6.1 Applicable Criterion for Benthic Impairment

The General Standard**,** as defined in Virginia state law 9 VAC 25-260-20, states:

> *A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

The General Standard is implemented by VADEQ through application of the modified Rapid Bioassessment Protocol II (RBP II). Using the modified RBP II, the health of the benthic macroinvertebrate community is typically assessed through measurement of eight biometrics (Table 6.1), which measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level (Barbour, 1999).

Each biometric measured at a target station is compared to the same biometric measured at a reference (not impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.,* not impaired, slightly impaired, moderately impaired, or severely impaired).

Table 6.1 Components of the modified RBP II Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index (MFBI)	↓
Scraper to Filtering Collector Ratio (SC/CF)	↑
EPT / Chironomid Ratio (EPT/CHI ABUND)	↑
% Contribution of Dominant Family (% DOM)	↓
EPT Index	↑
Community Loss Index (COMM. LOSS INDEX)	↓
Shredder to Total Ratio (SH/TOT)	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

6.2 Benthic Assessment – Knox Creek

Knox Creek was initially listed on the *1996 303(d) TMDL Priority List* as not supporting aquatic life. All VADEQ and DMME biological and ambient water quality monitoring stations on Knox Creek are shown in Table 6.2 and Figure 6.1.

Table 6.2 Benthic and ambient monitoring stations on Knox Creek.

Station	Station Type[1]	River Mile
6AKOX006.52	VADEQ-Ambient	6.52
MPID 4392	DMME Permit Monitoring Site	7.50
MPID 6020033	DMME Permit Monitoring Site	8.44
6AKOX008.51*	VADEQ-Biological	8.51
MPID 6020042	DMME Permit Monitoring Site	8.99
MPID 6020087	DMME Permit Monitoring Site	9.00
MPID 6084658	DMME Permit Monitoring Site	9.23
MPID 6084668	DMME Permit Monitoring Site	9.24
MPID 6020086	DMME Permit Monitoring Site	9.37
MPID 6084662	DMME Permit Monitoring Site	9.53
MPID 6020044	DMME Permit Monitoring Site	10.07
MPID 6020037	DMME Permit Monitoring Site	10.17
MPID 6020085	DMME Permit Monitoring Site	10.52
MPID 6020074	DMME Permit Monitoring Site	10.56
MPID 6020016	DMME Permit Monitoring Site	10.96
MPID 6020004	DMME Permit Monitoring Site	11.02
MPID 6084618	DMME Permit Monitoring Site	11.05
MPID 6084617	DMME Permit Monitoring Site	11.28
MPID 6085097	DMME Permit Monitoring Site	12.03
6AKOX014.17	VADEQ-Ambient	14.17
MPID 5054	DMME Permit Monitoring Site	20.55
MPID 5052	DMME Permit Monitoring Site	20.73

* Formerly 6AKOX000.10

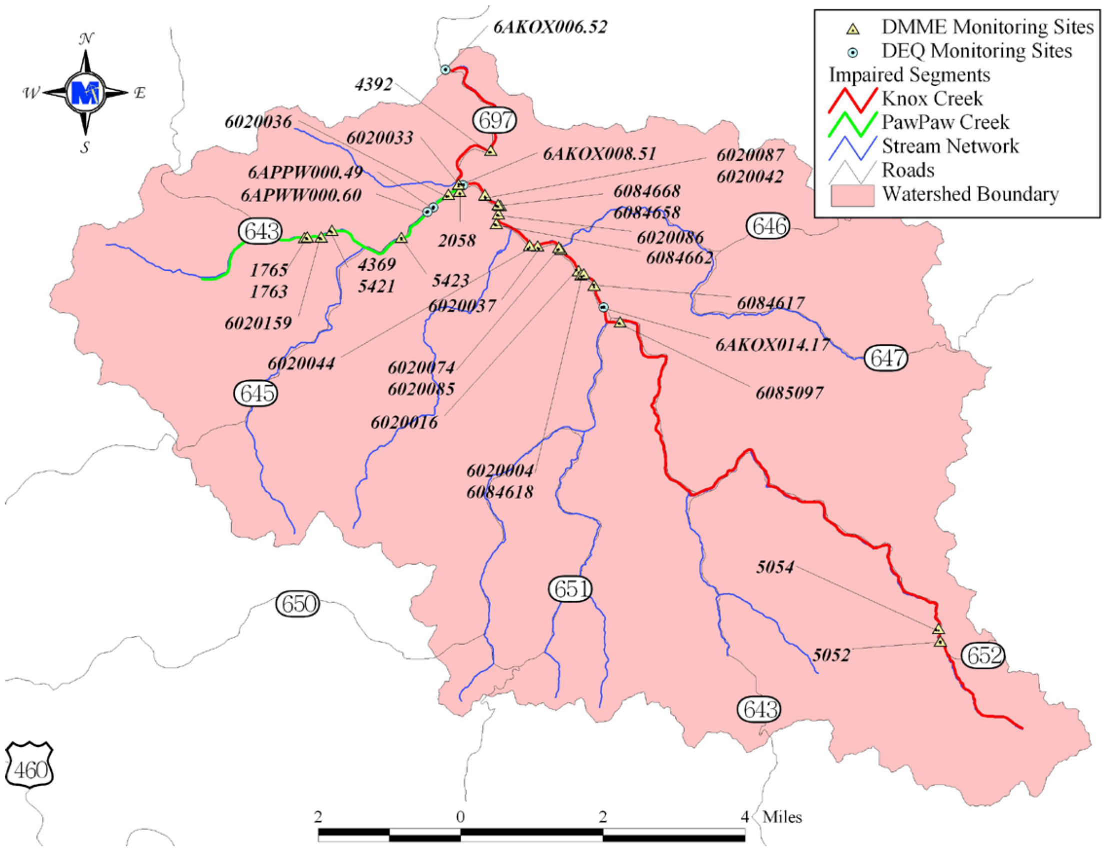

Figure 6.1 **Biological and ambient water quality monitoring stations on Knox Creek and Pawpaw Creek.**

Three modified RBP II benthic surveys were performed by the VADEQ on December 4, 1992, February 13, 1993 and May 3, 2005 at benthic monitoring stations 6AKOX008.51. The results of the modified RBP II benthic monitoring surveys are presented in Table 6.3. The table indicates that the surveys found moderately and slightly impaired conditions.

Table 6.3 **Modified RBP II biological monitoring data for station 6AKOX008.51 on Knox.**

Date	Assessment	Reference Station
12/4/1992	Moderately Impaired	6ADIS002.80
12/13/1993	Moderately Impaired	6ADIS002.80
5/3/2005	Slightly Impaired	6ADIS002.80

An alternative method to the modified RBP II is the Virginia Stream Condition Index (VASCI). The VASCI is being developed, and data is being collected to calibrate and further validate the VASCI method. Eight biometrics are obtained, with higher scores indicating a healthier benthic community. The advantage of the VASCI is that the score does not depend upon values from a reference station. The VASCI has an impairment threshold of 61.3 and the scores for the VADEQ surveys are presented in Table 6.4. Figure 6.2 is a graphical representation of the VASCI scores for VADEQ monitoring station 6AKOX008.51 and the reference station 6ADIS002.80 on Dismal Creek. Both scores at station 6AKOX008.51 were below the impairment threshold of 61.3.

Table 6.4 VASCI biological monitoring scores for station 6AKOX008.51 on Knox Creek.

Metric	12/4/92	2/13/93	5/3/2005
Richness Score	40.9	50.0	40.91
EPT Score	27.3	36.4	36.36
%Ephem Score	91.2	5.3	64.03
%PT-H* Score	0.0	48.9	0.00
%Scraper Score	71.2	77.1	12.06
%Chironomidae Score	92.2	88.0	51.40
%2Dom Score	50.9	54.9	20.23
%MFBI Score	82.9	83.9	72.70
VASCI Score	**57.1**	**55.6**	**37.21**

*%PT – Hydropsychidae

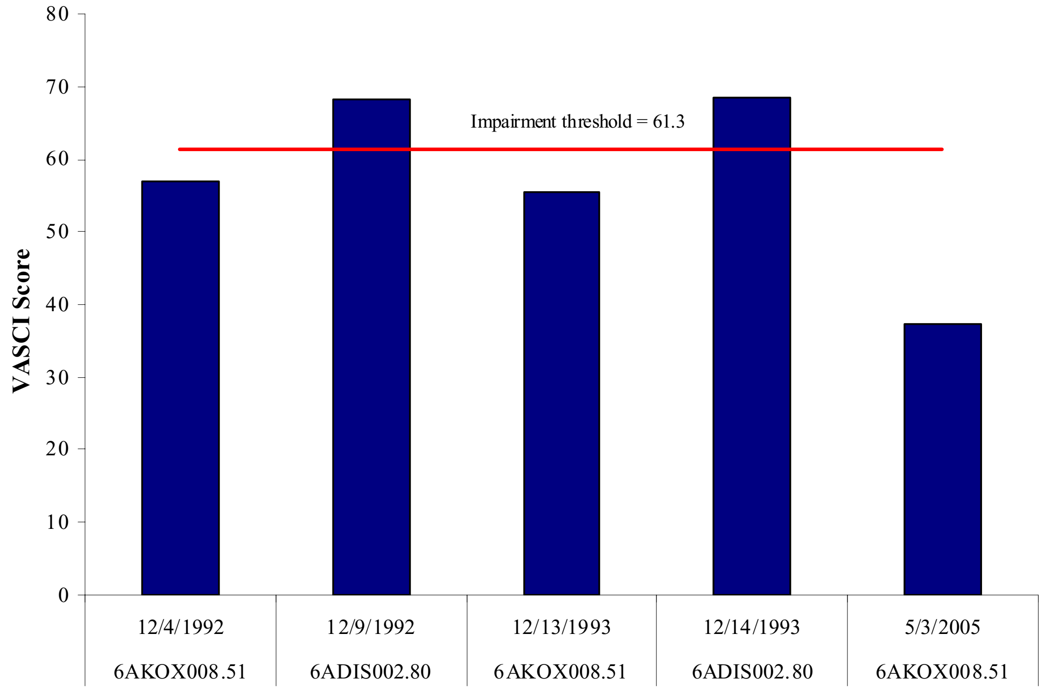

Figure 6.2 VASCI biological monitoring scores for VADEQ benthic monitoring station 6AKOX008.51 on Knox Creek and 6ADIS002.80 on Dismal Creek.

On December 22, 2004, Gress Engineering performed additional benthic surveys at two sites on Knox Creek under contract with DMME (Table 6.5 and Figure 6.3). Detailed results of the surveys are shown in Table 6.6 and Figure 6.4.

Table 6.5 Gress Engineering benthic monitoring stations on Knox Creek.

Station	River Mile	Location
KC-1	6.23	Near State Line
KC-2	11.96	At Hurley

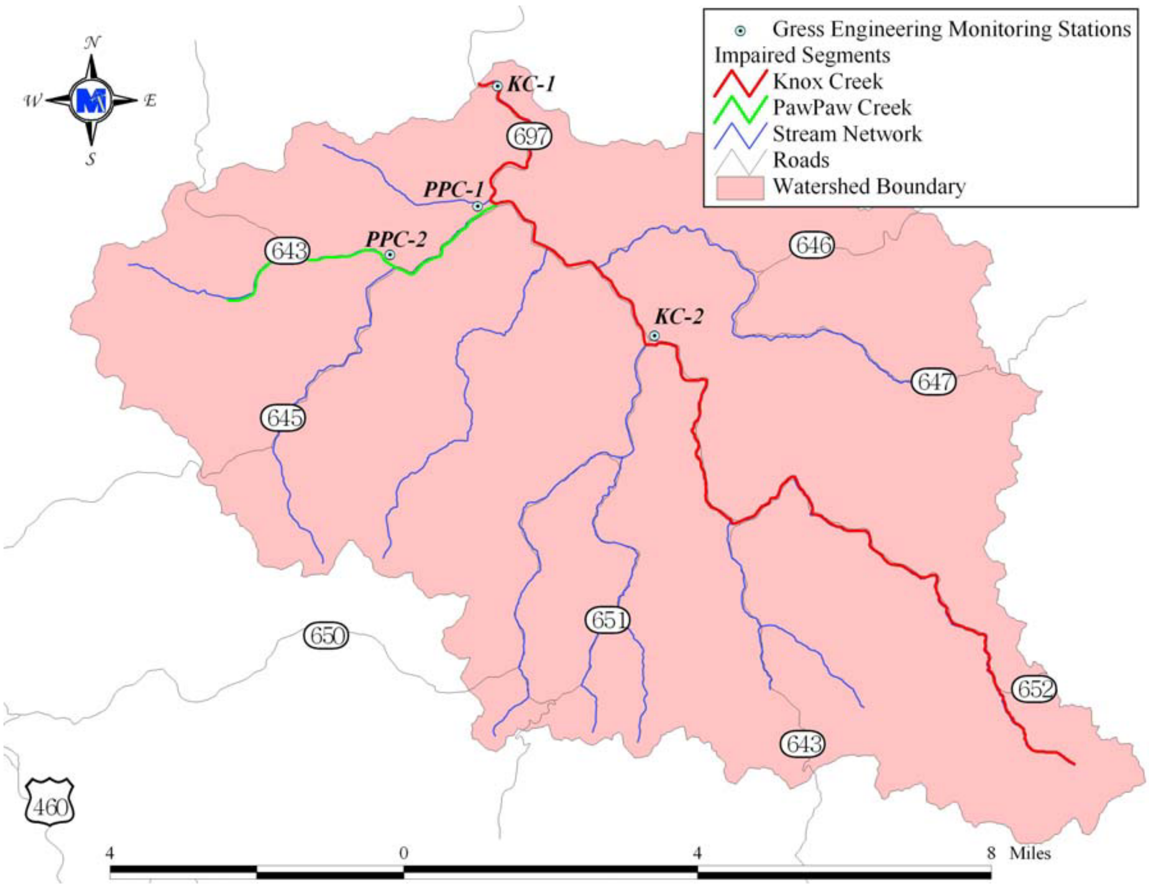

Figure 6.3 Location of Gress Engineering biological monitoring stations on Knox Creek and Pawpaw Creek.

Table 6.6 VASCI biological monitoring scores for Gress Engineering biological monitoring stations on Knox Creek.

Station Date Metric	KC-1 12/22/04	KC-2 12/22/04
Richness Score	40.91	63.64
EPT Score	45.45	54.55
%Ephem Score	27.19	31.03
%PT-H* Score	14.41	1.62
%Scraper Score	24.81	19.06
%Chironomidae Score	98.72	98.27
%2Dom Score	42.55	25.78
%MFBI Score	72.02	68.15
VASCI Score	**45.76**	**45.26**

*%PT – Hydropsychidae

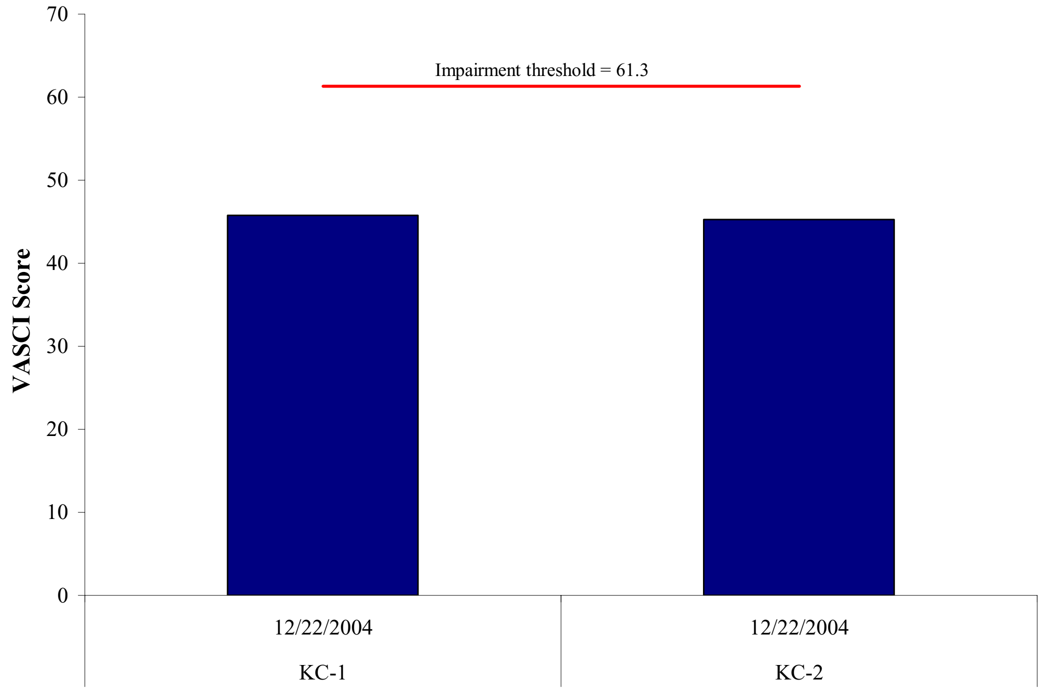

Figure 6.4 VASCI biological monitoring scores for Gress Engineering biological monitoring stations on Knox Creek

On July 31, 2002, the Kentucky Department of Environmental Protection (DEP) performed a benthic survey on Knox Creek at the Virginia/Kentucky state line (6AKOX006.52). The VASCI score for this survey was 63.25, which is just above the impairment threshold of 61.3 (Table 6.7).

Table 6.7 VASCI biological monitoring scores for Kentucky DEP monitoring at station 6AKOX006.52 on Knox Creek.

Metric	7/31/2002
Richness Score	59.09
EPT Score	63.64
%Ephem Score	84.83
%PT-H Score	7.49
%Scraper Score	46.24
%Chironomidae Score	96.67
%2Dom Score	62.53
%MFBI Score	85.49
VASCI Score	**63.25**

6.3 Benthic Assessment – Pawpaw Creek

All biological and ambient water quality monitoring stations on Pawpaw Creek are shown in Table 6.8 and Figure 6.1. Modified RBP II benthic surveys were performed by VADEQ at 6APPW000.60 in 1992 and on May 3, 2005. Table 6.9 shows the results of the May 2005 survey; however, the results from 1992 are not available. The table indicates that slightly impaired conditions were found compared to the reference stream Dismal Creek at river mile 2.80.

Table 6.8 Benthic and ambient monitoring stations on Pawpaw Creek.

Station	Station Type[1]	River Mile
2058	DMME Permit Monitoring Site	0.10
6020036	DMME Permit Monitoring Site	0.29
6APPW000.49	VADEQ Ambient	0.49
6APPW000.60	VADEQ Biological	0.60
5423	DMME Permit Monitoring Site	1.18
4369	DMME Permit Monitoring Site	2.33
5421	DMME Permit Monitoring Site	2.34
6020159	DMME Permit Monitoring Site	2.53
1763	DMME Permit Monitoring Site	2.71
1765	DMME Permit Monitoring Site	2.75

[1]Bio: Biological, SS: Special study, Ambient: Ambient water quality, FT: Fish Tissue
*Station with less than nine data points.

Table 6.9 Modified RBP II biological monitoring results for VADEQ station 6APPW000.49 on Pawpaw Creek.

Date	Assessment	Reference Station
5/3/2005	Slightly Impaired	6ADIS002.80

The VASCI score for the VADEQ survey is presented in Table 6.10. The VASCI score was below the impairment threshold of 61.3.

Table 6.10 VASCI data for VADEQ station 6APPW000.60 on Pawpaw Creek.

Metric	5/3/05
Richness Score	50.00
EPT Score	27.27
%Ephem Score	14.50
%PT-H* Score	0.00
%Scraper Score	30.47
%Chironomidae Score	48.89
%2Dom Score	49.70
%MFBI Score	63.40
VASCI Score	**35.5**

*%PT – Hydropsychidae

On December 22, 2004 Gress Engineering performed additional benthic surveys at two sites on Pawpaw Creek under contract with DMME (Table 6.11 and Figure 6.3). Detailed results of the surveys are shown in Table 6.12 and Figure 6.5.

Table 6.11 Gress Engineering benthic monitoring stations on Pawpaw Creek.

Station	River Mile	Location
PP-1	0.31	Near Mouth
PP-2	1.86	Above Left Fork Pawpaw Creek

Table 6.12 VASCI biological monitoring scores for Gress Engineering biological monitoring stations on Pawpaw Creek.

Station Date Metric	PPC-1 12/22/04	PPC-2 12/22/04
Richness Score	54.55	50.00
EPT Score	45.45	45.45
%Ephem Score	12.98	5.26
%PT-H Score	1.06	1.29
%Scraper Score	7.94	3.72
%Chironomidae Score	98.86	99.08
%2Dom Score	22.96	11.30
%MFBI Score	62.83	60.38
VASCI	**38.33**	**34.56**

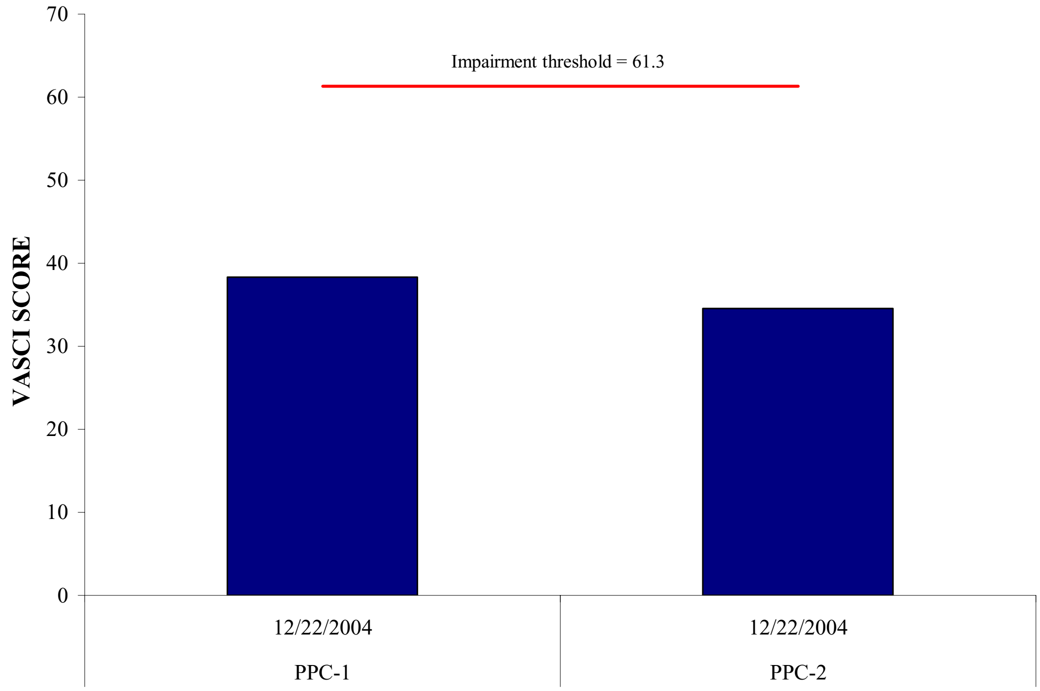

Figure 6.5 VASCI biological monitoring scores for Gress Engineering biological monitoring stations on Pawpaw Creek

6.4 Habitat Assessments

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.,* by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.,* due to land use changes in the watershed such as clearing large areas).

Habitat assessments are normally carried out as part of the benthic sampling. The overall habitat score is the sum of ten individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score for a sampling site are shown in Table 6.13.

Table 6.13 Classification of habitat metrics based on score.

Habitat Metric	Optimal	Sub-optimal	Marginal	Poor
Embeddedness	16 - 20	11 – 15	6 - 10	0 - 5
Epifaunal Substrate	16 - 20	11 – 15	6 - 10	0 - 5
Pool Sediment	16 - 20	11 – 15	6 - 10	0 - 5
Flow	16 - 20	11 – 15	6 - 10	0 - 5
Channel Alteration	16 - 20	11 – 15	6 - 10	0 - 5
Riffles	16 - 20	11 – 15	6 - 10	0 - 5
Velocity	16 - 20	11 – 15	6 - 10	0 - 5
Bank Stability	18 - 20	12 – 16	6 - 10	0 - 4
Bank Vegetation	18 - 20	12 – 16	6 - 10	0 - 4
Riparian Vegetation	18 - 20	12 – 16	6 - 10	0 - 4

6.4.1 Habitat Assessment at Biological Monitoring Stations – Knox Creek

Habitat assessment for Knox Creek includes an analysis of habitat scores recorded by the VADEQ biologist on May 3, 2005. The VADEQ habitat assessment on Knox Creek is displayed in Table 6.14. Riparian Vegetation is a measure of the width of the natural riparian zone. A healthy riparian zone acts as a buffer for pollutants running off the land, helps prevent erosion, and provides habitat. The Riparian Vegetation around Knox Creek scored in the marginal category and the Bank Stability scored in the poor category. Bank Stability is an indicator of how susceptible to erosion the stream bank is. A poor score indicates that more than 60% of the streambank has areas of erosion that contribute large amounts of sediment during times of high stream flow.

Table 6.14 Habitat scores for VADEQ monitoring station 6AKOX008.51 on Knox Creek on 5/3/2005.

Habitat Metric	Score
Embeddedness	15
Epifaunal Substrate	18
Pool Sediment	14
Flow	18
Channel Alteration	16
Riffles	14
Velocity	15
Bank Stability	4
Bank Vegetation	14
Riparian Vegetation	9

Table 6.15 shows the habitat scores for the Kentucky DEP benthic survey at 6AKOX006.52 on July 31, 2002. In general the habitat scores were very good with the exception of pool sediment, which was marginal.

Table 6.15 Habitat scores for 6AKOX006.52 on July 31, 2002 reported by the Kentucky DEP on 7/31/2002.

Habitat Metric	Score
Embeddedness	15
Epifaunal Substrate	15
Pool Sediment	7
Flow	15
Channel Alteration	16
Riffles	11
Velocity	16
Bank Stability	15
Bank Vegetation	16
Riparian Vegetation	16

6.4.2 Habitat Assessment at Biological Monitoring Stations – Pawpaw Creek

The habitat assessment for Pawpaw Creek includes an analysis of habitat scores recorded by the VADEQ biologist on May 3, 2005 (Table 6.16). The Sediment habitat metric was in the marginal category, which is indicative of large-scale movements of sediment in the stream and an unstable environment for the macroinvertebrate population. The marginal Sediment Deposition score indicates that 30 to 50% of the pool bottom is covered with fine sediment. In addition, the Bank Stability score was poor indicating that more than 60% of the streambank has areas of erosion, which contribute to the sediment problems previously discussed.

Table 6.16 Habitat scores at VADEQ benthic monitoring station 6APPW000.60 on Pawpaw Creek on 5/3/2005.

Metric	Score
Channel Alteration	16
Bank Stability	6
Bank Vegetation	14
Embeddedness	15
Flow	16
Riffles	15
Riparian Vegetation	14
Sediment Deposition	9
Epifaunal Substrate	15
Velocity	10

6.5 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream water quality data throughout the Knox Creek and Pawpaw Creek watersheds. An examination of data from water quality stations used in the Section 305(b) assessment and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

6.5.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information for Knox Creek are:

- Data collected at two VADEQ stations, and
- Data collected at 19 sites monitored by private coal mining companies for mining permit application or compliance and supplied by DMME.

The primary sources of available water quality information for Pawpaw Creek are:

- Data collected at one VADEQ station,
- Data collected at eight sites monitored by private coal mining companies for mining permit application or compliance and supplied by DMME.

Each station included in the DMME permit-monitoring database has been assigned unique MPIDs numbers.

6.5.1.1 VADEQ Water Quality Monitoring – Knox Creek

VADEQ has monitored water quality recently at two stations on Knox Creek (Table 6.17). The locations of these stations are shown in Figure 6.1. The data is summarized in Tables 6.18 and 6.19.

Table 6.17 VADEQ monitoring stations on Knox Creek.

Station	Type	Data Record	Comments
6AKOX006.52	Ambient	1/1990 – 8/2004	
6AKOX014.17	Ambient	7/2001 – 6/2003	12 monitoring events

Table 6.18 In-stream water quality data at 6AKOX006.52 in Knox Creek (1/1990 – 8/2004).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25C Micromho	438.22	199.74	854.71	144.5	415	83
Dissolved Oxygen, mg/L	10.57	1.92	15.1	7.09	10.38	60
Field pH, standard units	7.88	0.43	8.65	6.47	7.92	82
Temperature, Celsius	13.77	7.45	26	1.08	11.6	82
Alkalinity, Total, mg/L	71.1	45.9	325	19.6	68.4	60
BOD, mg/L	1.5	0.76	4	1	1	26
Carbon, Total Organic, mg/L as C	2.17	1.35	7.2	0.67	1.86	36
Chloride, Total, mg/L	10.9	8.32	52	1.9	10.3	55
COD High Level, mg/L	20.64	79.52	517	1.5	8	41
Fluoride, Total, mg/L	0.15	0.04	0.23	0.1	0.15	10
Hardness, calculated, mg/L	215.1	72.3	279.75	108.52	247.45	7
NH3+NH4-N, Total, mg/L	0.05	0.02	0.08	0.04	0.04	6
NO2-N, Total, mg/L as N	0.02	0.01	0.05	0.01	0.01	21
NO3-N, Total, mg/L as N	0.41	0.27	1.24	0.04	0.42	58
Nitrogen, Total Kjeldahl, mg/L	0.18	0.12	0.7	0.1	0.1	67
Phosphorus, dissolved orthoP, mg/L as P	0.02	0.01	0.04	0.01	0.02	13
Phosphorus, Total in orthoP, mg/L P	0.04	0.09	0.54	0.01	0.02	31
Phosphorus, Total, mg/L P	0.03	0.04	0.21	0.01	0.02	57
Sulfate, Total, mg/L	155.67	79.3	415	20.3	147.5	60
Total Hardness CACO3, mg/L	186.1	77.34	343	64.6	178.5	72
Solids, Total, mg/L	342.44	142.69	616	138	313	72
Solids, Total suspended, mg/L	28.96	55.12	312	1	12	51
Solids, Inorganic Suspended, mg/L	27.46	50.45	269	1	10.5	46
Solids, Total dissolved, mg/L -	310.63	137.9	536	110	287.5	38
Solids, Total Inorganic, mg/L	284.24	121.98	528	114	261	72
Solids, Total organic, mg/L	58.21	27.11	136	8	53.5	72
Solids, Total organic suspended, mg/L	5.66	8.28	43	1	3	32
Turbidity Hach Turbidimeter , FTU	15.75	31.28	195	1.68	5.92	41
Turbidity, JTU	9.38	9.2	40	1.2	5.4	21
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		Water Column Metals				
Calcium, Total, µg/L	41,285	25,732	59,480	23,090	41,285	2
Copper, Total, µg/L	16.67	4.72	20	13.33	16.67	2
Magnesium, Total, mg/L	23,207	7,629	29,750	12,350	26,845	6
Manganese, µg/L	67.25	51.27	171.75	17.64	54.48	7
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		Sediment Metals				
Antimony, mg/kg dry wt	7.0	0.0	7.0	7.0	7.0	2
Arsenic , mg/kg dry wt	5.98	1.3	8	4.6	5.65	6
Aluminum, mg/kg dry wt	7,797	4,581	15,400	3,750	5,020	7

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.18 In-stream water quality data at 6AKOX006.52 in Knox Creek (1/1990 – 8/2004) (cont).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
		Sediment Metals				
Fe, mg/kg dry wt Fe	20,843	5,318	29,500	14,100	19,100	7
Manganese, mg/kg dry wt	514.43	209.94	851	260	418	7
Chromium, mg/kg dry wt	11.97	4.82	21	6	10.25	10
Copper, mg/kg dry wt	18.85	8.98	34	11	16.9	11
Lead, mg/kg dry wt	17.05	11.65	49.3	8	15.6	11
Nickel, mg/kg dry wt	26.19	15.12	63	9.42	21	11
Zinc, mg/kg dry wt	76.2	48.78	180	12	59.1	11

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.19 In-stream water quality data at 6AKOX014.17 in Knox Creek (7/2001 - 6/2003).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25C Micromho	372	182	687	145	312	12
Dissolved Oxygen, mg/L	10.32	1.12	11.67	8.33	10.42	12
Field pH, standard units	8.09	0.4	8.57	7.33	8.25	12
Temperature, Celsius	16.33	6.49	28	7.67	15.25	12
Nitrogen, Total Kjeldahl, mg/L	0.17	0.07	0.3	0.1	0.2	9
NO2-N, Total, mg/L as N	0.06	0.09	0.17	0.01	0.01	3
NO3-N, Total, mg/L as N	0.42	0.26	0.82	0.07	0.36	10
Phosphorus, Total in OrthoP, mg/L P	0.04	0.04	0.1	0.02	0.02	4
Phosphorus, Total, mg/L P	0.04	0.08	0.28	0.01	0.02	12
Solids, Inorganic suspended, mg/L	229.83	500.66	1,250	5	16	6
Solids, Total dissolved, mg/L	234.33	131.39	461	105	183	6
Solids, Total inorganic, mg/L	333.42	361.22	1,423	92	204	12
Solids, Total suspended, mg/L	255.17	554.98	1,386	6	18	6
Solids, Total, mg/L	393.42	390.28	1,561	114	243.5	12
Solids, Volatile suspended, mg/L	49.67	74.85	136	3	10	3
Solids, Volatile, mg/L	60	31.17	138	22	44.5	12
Total Hardness CACO3, mg/L	150.01	72.33	264	44.4	134.5	12
Turbidity Hach Turbidimeter, FTU	168.39	489.41	1,560	0.8	7.2	10
Turbidity Lab, NTU	1.65	0.78	2.2	1.1	1.65	2

[1]SD: standard deviation, [2]N: number of sample measurements.

6.5.1.2 VADEQ Water Quality Monitoring– Pawpaw Creek

VADEQ has monitored water quality recently at one site on Pawpaw Creek (Table 6.20). The location of this station is shown in Figure 6.3. The data for this station is summarized in Table 6.21. The sampling at this station represents a single sediment-sampling event with field parameters.

Table 6.20 VADEQ monitoring station on Pawpaw Creek.

Station	Type	Data Record	# Samples
6APPW000.49	Special Study	8/2004	1

Table 6.21 In-stream water quality data at 6APPW000.49 on Pawpaw Creek (8/2004).

Water Quality Constituent	Value	N[1]
Conductivity, 250C Micromho	484	1
Dissolved Oxygen, mg/L	7.38	1
Field pH, standard units	8.03	1
Temperature, Celsius	21.12	1
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Sediment Metals		
Chromium, mg/kg dry wt	7.63	1
Copper, mg/kg dry wt	10	1
Fe, mg/kg dry wt Fe	15,400	1
Lead, mg/kg dry wt	9.05	1
Manganese, mg/kg dry wt	402	1
Nickel, mg/kg dry wt	12.9	1
Zinc, mg/kg dry wt	46.8	1
Aluminum, mg/kg dry wt	4,790	1

[1]N: number of sample measurements.

6.5.1.3 Mine Permit Application/Compliance Monitoring – Knox Creek

There is ambient water quality monitoring data associated with 19 coal-mining sites on Knox Creek. DMME requires in-stream monitoring from coal mining related permittees throughout the watershed. Sample timing varied based on the permit that the sample was intended to support. DMME requires their permittees to monitor pH, acidity, total iron, total manganese, total dissolved solids, total suspended solids, sulfate, temperature, alkalinity and conductivity. Stations on the mainstem of Knox Creek where monitoring data was supplied by the DMME are shown in Table 6.22 and Figure 6.1. The data from these stations were used in the stressor identification in Chapter 8.

Table 6.22 Monitoring stations on Knox Creek from data supplied by DMME.

MPID	River Mile	Data Record Begin	Data Record End
4392	7.50	10/2001	12/2004
6020033	8.44	10/1995	12/2004
6020042	8.99	1/1996	12/2004
6020087	9.00	4/1997	12/2004
6084658	9.23	3/1996	12/2004
6084668	9.24	3/1995	10/1998
6020086	9.37	1/1996	12/2004
6084662	9.53	12/1997	6/2004
6020044	10.07	1/1996	12/2004
6020037	10.17	1/1995	6/1996
6020085	10.52	1/1996	12/2004
6020074	10.56	1/1996	12/2004
6020016	10.96	1/1995	12/2004
6020004	11.02	1/1996	12/2004
6084618	11.05	5/1996	12/2004
6084617	11.28	1/1995	12/2004
6085097	12.03	2/1995	2/1995
5054	20.55	5/2003	12/2004
5052	20.73	5/2003	12/2004

Tables 6.23 through 6.41 show summaries of the water quality data collected at each of the 19 in-stream MPIDs. Abbreviations used in these tables include: TDS (Total Dissolved Solids), TSS (Total Suspended Solids), gallon per minute (GPM). All flow values that contributed to these summaries were estimated and were therefore not used in modeling hydrology.

Table 6.23 In-stream water quality data at MPID 4392 (10/01—12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	547	208	970	172	545	39
Field pH, standard units	7.94	0.27	8.60	7.30	7.90	39
Iron, Total, µg/L	0.19	0.15	0.90	0.10	0.10	39
Sulfate, Total, mg/L	198	92	412	44	184	39
Alkalinity, Total, mg/L	77	32	143	33	82	39
TDS, mg/L	383	159	742	126	364	39
Temperature, Celsius	15.90	6.89	27.00	2.00	16.00	39
TSS , mg/L	9	18	96	2	4	39
Acidity, mg/L	1.00	0.00	1.00	1.00	1.00	39
Flow, GPM	6,421	3,452	1,389	1,800	5,107	39
Manganese, Total, µg/L as Mn	0.14	0.15	0.70	0.10	0.10	16

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.24 In-stream water quality data at MPID 6020033 (1/96-12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	330	127	900	186	306	106
Field pH, standard units	7.30	0.29	8.10	6.20	7.30	107
Iron, Total, µg/L	0.15	0.09	0.60	0.10	0.10	50
Sulfate, Total, mg/L	142	130	690	29	128	107
Alkalinity, Total, mg/L	92	35	168	34	82	107
TDS , mg/L	197	101	920	97	181	67
Temperature, Celsius	17.72	5.39	47.00	3.00	18.00	106
TSS , mg/L	18.46	23.19	162.00	2.00	12.00	106
Acidity, mg/L	17.76	6.27	47.00	9.00	17.00	38
Flow, GPM	4,220	4,712	19,100	8	3,000	107
Manganese, Total, µg/L as Mn	0.12	0.04	0.20	0.10	0.10	5

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.25 In-stream water quality data at MPID 6020042 (01/96—12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	452	205	1,020	120	396	107
Field pH, standard units	7.68	0.47	8.80	6.70	7.70	108
Iron, Total, µg/L	0.25	0.38	3.50	0.10	0.20	106
Sulfate, Total, mg/L	156	88	377	4	136	107
Alkalinity, Total, mg/L	70	31	143	17	66	108
TDS, mg/L	306	155	738	34	272	107
Temperature, Celsius	14.15	6.37	30.00	2.00	13.00	108
TSS, mg/L	8.99	13.52	102.00	0.60	4.00	106
Acidity, mg/L	1.02	0.13	2.00	1.00	1.00	61
Flow, GPM	5,388	3,556	14,000	330	4,260	108
Manganese, Total, µg/L as Mn	0.10	0.02	0.20	0.10	0.10	24

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.26 In-stream water quality data at MPID 6020087 (4/1997—12/2004).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	461	207	1,020	140	418	93
Field pH, standard units	7.76	0.45	8.80	6.70	7.80	93
Iron, Total, µg/L	0.24	0.38	3.50	0.10	0.20	92
Sulfate, Total, mg/L	164	86	377	34	139	93
Alkalinity, Total, mg/L	73	32	143	17	68	93
TDS, mg/L	317	154	738	100	292	93
Temperature, Celsius	14.77	6.58	30.00	2.00	13.50	92
TSS, mg/L	8.63	13.80	102.00	2.00	4.00	92
Acidity, mg/L	1.02	0.13	2.00	1.00	1.00	63
Flow, GPM	5,635	3,715	14,000	330	4,400	93
Manganese, Total, µg/L as Mn	0.11	0.02	0.20	0.10	0.10	20

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.27 In-stream water quality data at MPID 6084658 (3/96 - 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	1,099	492	1,990	355	1,010	11
Field pH, standard units	7.53	0.55	9.00	5.20	7.50	80
Iron, Total, µg/L	1.01	1.73	14.00	0.10	0.43	80
Temperature, Celsius	14.17	6.65	28.00	4.50	11.50	21
TSS, mg/L	11.05	10.23	80.30	2.40	8.00	80
Flow, GPM	52.38	47.50	255.50	2.00	35.00	80
Manganese, Total, µg/L as Mn	0.45	0.37	1.90	0.10	0.40	79
Settleable Solids, mg/L	0.40	0.00	0.40	0.40	0.40	17

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.28 In-stream water quality data at MPID 6084668 (3/95 - 10/98).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	1,327	326	1,975	805	1,295	24
Field pH, standard units	7.34	0.19	8.40	7.10	7.30	44
Iron, Total, µg/L	0.15	0.06	0.35	0.10	0.15	42
Temperature, Celsius	13.34	5.19	30.00	5.00	12.00	28
TSS, mg/L	6.66	3.45	17.00	1.60	5.50	44
Flow, GPM	24.23	13.50	54.50	3.00	22.50	44
Manganese, Total, µg/L as Mn	0.24	0.22	1.25	0.10	0.20	41

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.29 In-stream water quality data at MPID 6020086 (1/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	457	208	1,092	150	408	108
Field pH, standard units	7.65	0.45	8.60	6.50	7.70	108
Iron, Total, µg/L	0.22	0.18	1.10	0.10	0.20	105
Sulfate, Total, mg/L	151	87	374	6	127	108
Alkalinity, Total, mg/L	71	31	143	17	66	108
TDS, mg/L	307	153	728	52	272	108
Temp, Celsius	14.08	6.40	30.00	2.00	12.00	108
TSS, mg/L	8.58	10.21	64.00	0.20	4.00	105
Acidity, mg/L	1.00	0.00	1.00	1.00	1.00	60
Flow, GPM	5,260	3,500	13,900	320	4,151	108
Manganese, Total, µg/L as Mn	0.10	0.02	0.20	0.10	0.10	22

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.30 In-stream water quality data at MPID 6084662 (12/97 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	350		350	350	-	1
Field pH, standard units	7.55	0.40	8.20	6.80	7.50	18
Iron, Total, µg/L	0.38	0.41	1.50	0.10	0.20	11
Temperature, Celsius	12.50	4.20	17.00	8.00	12.50	4
TSS, mg/L	10.83	9.41	30.40	1.00	7.00	12
Flow, GPM	8.82	7.59	30.00	1.00	6.50	17
Manganese, Total, µg/L as Mn	0.23	0.23	0.50	0.10	0.10	3
Conductivity, 25^0C Micromho	2.10	5.61	19.00	0.40	0.40	11

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.31 In-stream water quality data at MPID 6020044 (1/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	456	180	980	130	438	108
Field pH, standard units	7.64	0.45	8.60	6.30	7.70	108
Iron, Total, µg/L	0.22	0.18	1.30	0.10	0.20	105
Sulfate, Total, mg/L	160	81	350	2	150	108
Alkalinity, Total, mg/L	71	31	171	20	72	108
TDS, mg/L	313	137	736	28	315	108
Temperature, Celsius	14.31	6.30	28.00	2.00	13.00	108
TSS, mg/L	7.28	8.63	58.00	0.80	4.00	104
Acidity, mg/L	1.00	0.00	1.00	1.00	1.00	60
Flow, GPM	4,952	3,716	24,000	280	3,740	108
Manganese, Total, µg/L as Mn	0.11	0.04	0.30	0.10	0.10	29

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.32 In-stream water quality data at MPID 6020037 (1/95 – 6/96).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	467	178	980	130	450	101
Field pH, standard units	7.68	0.43	8.60	6.90	7.80	101
Iron, Total, µg/L	0.21	0.16	1.30	0.10	0.20	98
Sulfate, Total, mg/L	168	77	350	20	152	101
Alkalinity, Total, mg/L	73	31	171	20	73	101
TDS, mg/L	321	135	736	28	324	101
Temperature, Celsius	14.56	6.43	28.00	2.00	13.00	101
TSS, mg/L	7.12	8.62	58.00	1.00	4.00	99
Acidity, mg/L	1.00	0.00	1.00	1.00	1.00	60
Flow, GPM	4,901	3,229	12,900	1,000	3,680	101
Manganese, Total, µg/L as Mn	0.11	0.05	0.30	0.10	0.10	27

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.33 In-stream water quality data at MPID 6020085 (1/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	432	187	897	140	396	108
Field pH, standard units	7.70	0.75	8.80	1.80	7.75	108
Iron, Total, µg/L	0.18	0.16	1.10	0.10	0.10	105
Sulfate, Total, mg/L	147	81	340	15	130	107
Alkalinity, Total, mg/L	69	31	136	18	67	107
TDS, mg/L	295	143	730	52	268	107
Temperature, Celsius	14.50	6.32	29.00	2.00	13.00	108
TSS, mg/L	6.72	5.84	30.00	0.20	4.00	103
Acidity, mg/L	1.03	0.26	3.00	1.00	1.00	60
Flow, GPM	4,611	3,176	12,800	813	3,500	108
Manganese, Total, µg/L as Mn	0.12	0.05	0.30	0.10	0.10	18

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.34 In-stream water quality data at MPID 6020074 (1/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	427	188	904	110	394	107
Field pH, standard units	7.70	0.47	8.70	6.90	7.70	107
Iron, Total, µg/L	0.19	0.18	1.50	0.10	0.20	101
Sulfate, Total, mg/L	141	76	322	15	126	107
Alkalinity, Total, mg/L	68	31	143	17	64	107
TDS, mg/L	291	149	722	2	258	107
Temperature, Celsius	14.66	6.43	30.00	2.00	13.00	107
TSS, mg/L	6.51	7.54	62.00	1.00	4.00	102
Acidity, mg/L	1.00	0.00	1.00	1.00	1.00	59
Flow, GPM	3,912	2,828	11,300	724	3,000	107
Manganese, Total, µg/L as Mn	0.12	0.05	0.30	0.10	0.10	19

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.35 In-stream water quality data at MPID 6020016 (1/95 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	480	233	1,337	125	440	105
Field pH, standard units	7.72	0.55	8.90	6.00	7.80	105
Iron, Total, µg/L	0.85	2.55	20.00	0.10	0.20	94
Sulfate, Total, mg/L	145	120	825	10	116	104
Alkalinity, Total, mg/L	65	31	145	8	61	105
TDS, mg/L	278	153	1,064	63	250	105
Temperature, Celsius	14.01	7.49	29.00	1.00	13.00	102
TSS, mg/L	39.55	120.94	869.00	1.00	6.00	88
Acidity, mg/L	1.21	0.80	4.00	1.00	1.00	14
Flow, GPM	4,649	13,205	86,209	10	325	93
Manganese, Total, µg/L as Mn	0.22	0.30	1.70	0.10	0.10	43

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.36 In-stream water quality data at MPID 6020004 (1/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	408	191	916	130	367	108
Field pH, standard units	7.76	0.51	9.00	6.80	7.70	108
Iron, Total, µg/L	0.29	1.04	10.60	0.10	0.10	104
Sulfate, Total, mg/L	133	77	312	11	114	108
Alkalinity, Total, mg/L	67	31	144	16	64	108
TDS, mg/L	280	146	740	2	279	108
Temperature, Celsius	14.44	6.26	28.00	3.00	13.00	108
TSS, mg/L	10.46	25.45	244.00	0.20	5.50	104
Acidity, mg/L	1.13	0.75	6.00	1.00	1.00	60
Flow, GPM	3,361	2,740	11,250	100	2,100	108
Manganese, Total, µg/L as Mn	0.12	0.05	0.30	0.10	0.10	17

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.37 In-stream water quality data at MPID 6084618 (5/96 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	645	744	1,761	256	281	4
Field pH, standard units	7.54	0.45	8.40	6.70	7.50	15
Iron, Total, µg/L	0.92	1.61	6.50	0.10	0.35	15
Temperature, Celsius	18.38	7.28	27.00	4.00	19.50	8
TSS, mg/L	25.63	41.44	163.00	2.00	7.50	15
Flow, GPM	12.80	16.08	60.00	1.00	5.00	15
Manganese, Total, µg/L as Mn	0.41	0.50	1.50	0.10	0.10	9

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.38 In-stream water quality data at MPID 6084617 (1/95 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	990	277	1,372	580	965	10
Field pH, standard units	7.40	0.41	8.70	6.25	7.40	102
Iron, Total, µg/L	0.32	0.62	5.90	0.10	0.20	97
Sulfate, Total, mg/L	244		244	244	-	1
Alkalinity, Total, mg/L	153	144	255	51	153	2
TDS, mg/L	601		601	601	-	1
Temperature, Celsius	15.08	8.66	49.00	1.00	15.00	69
TSS, mg/L	9.64	8.23	50.50	1.00	8.00	96
Acidity, mg/L	10.00		10.00	10.00	-	1
Flow, GPM	33	38	230	1	22	102
Manganese, Total, µg/L as Mn	0.71	1.14	9.20	0.10	0.40	93
Settleable Solids, mg/L	0.18	0.15	0.40	0.10	0.10	4

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.39 In-stream water quality data at MPID 6085097 (2/95).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	6.60		6.60	6.60	-	1
Flow, GPM	5.00		5.00	5.00	-	1
Settleable Solids, mg/L	0.10		0.10	0.10	-	1

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.40 In-stream water quality data at MPID 5054 (5/03 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	131	54	292	73	116	17
Field pH, standard units	7.45	0.64	8.20	5.80	7.50	17
Iron, Total, µg/L	0.16	0.10	0.40	0.10	0.10	11
Sulfate, Total, mg/L	35	23	110	6	27	17
Alkalinity, Total, mg/L	20	10	37	9	16	17
TDS, mg/L	92	51	212	34	90	17
Temperature, Celsius	16.18	4.29	22.00	7.00	17.00	17
TSS, mg/L	3.41	2.62	12.00	2.00	2.00	17
Acidity, mg/L	1.93	2.40	10.00	1.00	1.00	14
Flow, GPM	444	342	1,240	30	420	15
Manganese, Total, µg/L as Mn	0.10	0.00	0.10	0.10	0.10	2

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.41 In-stream water quality data at MPID 5052 (5/03 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Conductivity, 25°C Micromho	124	167	740	53	83	16
Field pH, standard units	7.41	0.68	8.30	6.20	7.45	16
Iron, Total, µg/L	0.17	0.09	0.40	0.10	0.15	14
Sulfate, Total, mg/L	30	36	130	9	15	16
Alkalinity, Total, mg/L	23	23	101	8	16	16
TDS, mg/L	66	33	148	20	60	16
Temperature, Celsius	16.06	4.12	21.00	8.00	17.00	16
TSS, mg/L	5	6	22	1	2	15
Acidity, mg/L	2.00	2.77	11.00	1.00	1.00	13
Flow, GPM	273	215	840	44	205	14
Manganese, Total, µg/L as Mn	0.10	-	0.10	0.10	-	1

[1]SD: standard deviation, [2]N: number of sample measurements.

6.5.1.4 Mine Permit Application/Compliance Monitoring – Pawpaw Creek

There is ambient water quality monitoring data associated with eight coal mining sites on Pawpaw Creek. DMME requires in-stream monitoring from coal mining related permittees throughout the watershed. Sample timing varied based on the permit that the sample was intended to support. The Pawpaw Creek DMME in-stream monitoring data is shown in Table 6.42 and Figure 6.1. The data from these stations were used in the stressor identification in Chapter 8.

Table 6.42 Monitoring stations on Pawpaw Creek from data supplied by DMME.

MPID	River Mile	Data Record Begin	Data Record End
2058*	0.10	04/96	4/96
6020036	0.29	10/95	12/04
5423	1.18	4/04	12/04
4369	2.33	10/01	9/04
5421	2.34	4/04	12/04
6020159	2.53	1/95	12/04
1763	2.71	10/95	9/02
1765	2075	10/95	9/02

*Only one data point, this station was not shown in the median graphs. There were no extreme values.

Tables 6.43 through 6.50 show summaries of the water quality data collected at each of the eight in-stream monitoring locations. Abbreviations used in these tables include:

TDS (Total Dissolved Solids), TSS (Total Suspended Solids), gallon per minute (GPM). All flow values that contributed to these summaries were estimated.

Table 6.43 In-stream water quality data at MPID 2058 (4/96).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.1	-	7.1	7.1	-	1
Temperature, Celsius	7.0	-	7.0	7.0	-	1
Conductivity, 25°C Micromho	90	-	90	90	-	1
Flow, GPM	33	-	33	33	-	1

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.44 In-stream water quality data at MPID 6020036 (10/95 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.3	0.3	7.9	6.3	7.3	105
Temperature, Celsius	15.8	5.7	26.0	1.0	16.0	103
Conductivity, 25°C Micromho	364	140	910	173	320	105
Sulfate, Total, mg/L	151.7	130.5	730.0	47.0	125.0	105
Alkalinity, Total, mg/L	94.8	35.6	166.0	32.0	84.0	105
TDS, mg/L	180	53	312	92	162	63
TSS, mg/L	20	24	165	2	14	104
Flow, GPM	4,338	4,686	19,000	22	2,613	104
Manganese, Total, µg/L as Mn	0.17	0.08	0.40	0.10	0.20	20
Iron, Total, µg/L	0.16	0.10	0.70	0.10	0.10	49
Acidity, mg/L	15.6	4.8	22.0	3.0	16.0	35

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.45 In-stream water quality data at MPID 5423 (4/04 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.7	0.6	8.6	6.8	7.6	9
Temperature, Celsius	23.1	3.9	29.0	17.0	23.0	9
Conductivity, 25°C Micromho	435	173	714	177	454	9
Alkalinity, Total, mg/L	84	50	169	34	75	9
Flow, GPM	1,295	478	2,175	833	1,100	9
Iron, Total, µg/L	0.51	0.56	1.70	0.10	0.30	9
Manganese, Total, µg/L as Mn	0.16	0.09	0.30	0.10	0.10	5
Sulfate, Total, mg/L	139	74	237	24	151	9
TDS, mg/L	300	120	460	140	296	9
TSS, mg/L	95	170	508	2	6	9

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.46 In-stream water quality data at MPID 4369 (10/01 – 9/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.4	0.2	7.9	7.0	7.4	36
Temperature, Celsius	18.4	4.0	27.0	9.0	19.0	36
Conductivity, 25°C Micromho	320	83	470	205	325	36
Alkalinity, Total, mg/L	133	37	208	56	132	36
Flow, GPM	74	54	250	12	60	36
Iron, Total, µg/L	0.18	0.13	0.60	0.10	0.10	25
Manganese, Total, µg/L as Mn	0.10	0.00	0.10	0.10	0.10	5
Sulfate, Total, mg/L	151	79	290	4	159	36
TDS, mg/L	171	45	258	98	171	36
TSS, mg/L	13	9	39	3	11	36

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.47 In-stream water quality data at MPID 5421 (4/04 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.7	0.4	8.4	7.1	7.7	9
Temperature, Celsius	23.9	3.4	29.0	20.0	24.0	9
Conductivity, 25°C Micromho	392	233	787	109	384	9
Alkalinity, Total, mg/L	73	35	126	34	76	9
Flow, GPM	748	416	1,560	217	770	8
Iron, Total, µg/L	0.51	0.67	1.90	0.10	0.20	8
Manganese, Total, µg/L as Mn	0.27	0.15	0.40	0.10	0.30	3
Sulfate, Total, mg/L	123	91	267	6	129	9
TDS, mg/L	270	142	498	80	270	9
TSS, mg/L	129	294	886	2	6	9

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.48 In-stream water quality data at MPID 6020159 (1/95 – 12/04).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	7.8	0.5	9.1	6.9	7.8	74
Temperature, Celsius	14.0	6.9	32.0	1.0	14.0	73
Conductivity, 25°C Micromho	446	371	3,070	113	380	73
Alkalinity, Total, mg/L	66	48	356	8	60	74
Flow, GPM	1,285	2,602	13,287	1	300	73
Iron, Total, µg/L	0.48	0.85	4.70	0.10	0.20	70
Manganese, Total, µg/L as Mn	0.14	0.17	1.00	0.10	0.10	32
Sulfate, Total, mg/L	111	73	425	7	100	73
TDS, mg/L	263	188	1,304	42	237	74
TSS, mg/L	32	94	584	1	9	63

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.49 In-stream water quality data at MPID 1763 (10/95 – 9/02).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	8.0	0.5	9.6	6.7	8.0	75
Temperature, Celsius	10.8	7.6	30.0	1.0	8.0	72
Conductivity, 25°C Micromho	520	233	894	135	548	75
Alkalinity, Total, mg/L	73	41	230	5	69	74
Flow, GPM	808	1,190	6,233	1	355	74
Iron, Total, µg/L	0.59	1.33	10.40	0.10	0.25	66
Manganese, Total, µg/L as Mn	0.12	0.06	0.30	0.10	0.10	14
Sulfate, Total, mg/L	158	106	440	18	135	73
TDS, mg/L	274	138	572	42	280	75
TSS, mg/L	42	151	1,108	1	10	57

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 6.50 In-stream water quality data at MPID 1765 (10/95 – 9/02).

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Field pH, standard units	8.0	0.5	10.4	6.6	8.0	76
Temperature, Celsius	11.0	7.4	29.0	1.0	8.5	74
Conductivity, 25°C Micromho	514	241	1,048	134	521	76
Alkalinity, Total, mg/L	70	40	233	16	65	76
Flow, GPM	860	1,238	5,343	1	240	75
Iron, Total, µg/L	0.94	3.34	25.40	0.10	0.20	62
Manganese, Total, µg/L as Mn	0.16	0.19	0.90	0.10	0.10	18
Sulfate, Total, mg/L	147	106	460	11	110	76
TDS, mg/L	291	183	1,129	42	276	76
TSS, mg/L	40	148	1,136	1	8	61

[1]SD: standard deviation, [2]N: number of sample measurements.

6.5.1.5 Fish Tissue and Sediment Sampling Results – Knox Creek

VADEQ performed special fish tissue and sediment sampling at several sites on the Knox Creek. Tables 6.51 through 6.54 show the results of these sampling events. Knox Creek is under a Virginia Department of Health (VDH) fish consumption ban due to PCB contamination; the PCB source is unknown. The ban includes the entire mainstem of Knox Creek and all of its tributaries. More information on the VDH ban can be found at http://www.vdh.state.va.us/HHControl/TennesseeBigSandy.asp. All metals, pesticides and other organic compounds were below VDH, VADEQ and EPA screening and action levels for fish tissue. In addition VADEQ collected 11 sediment samples during its routine monitoring from 4/1990 through 8/2004 at 6AKOX006.52, Table 6.55.

Table 6.51 Fish tissue sampling results for PCB from three VADEQ monitoring stations on Knox Creek.

Station	Date	Fish species name	VDH Action Level	Total PCB[1] ppb[2] wet weight basis
6AKOX008.11	07/23/97	Northern Hogsucker	50	219
6AKOX008.11	07/23/97	Smallmouth Bass	50	76
6AKOX008.11	07/23/97	Stoneroller	50	217
6AKOX022.00	10/06/03	Rainbow Trout	50	283
6AKOX022.00	10/06/03	Rainbow Trout	50	49
6AKOX022.00	10/06/03	Rainbow Trout	50	670
6AKOX022.00	10/06/03	Rainbow Trout	50	58
6AKOX022.00	10/06/03	Northern Hogsucker	50	69
6AKOX022.00	10/06/03	Creek Chub	50	178
6AKOX019.30	10/06/03	Rock Bass	50	95
6AKOX019.30	10/06/03	Northern Hogsucker	50	12,033
6AKOX019.30	10/06/03	Rainbow Trout	50	1,949
6AKOX019.30	10/06/03	Rainbow Trout	50	825
6AKOX019.30	10/06/03	Smallmouth Bass	50	6,190

[1]Total PCB = sum of polychlorinated biphenyl congeners, [2]ppb = parts per billion (aka - µg/kg or ng/g); wet weight basis, edible fillet

Table 6.52 Sediment metal sampling results from VADEQ monitoring station 6AKOX008.11 on Knox Creek (July 23, 1997).

Metal	PEC[1]	Value[2]
Aluminum	NA[3]	0.12
Silver	NA	1.2
Arsenic	33	11
Cadmium	4.98	0.2
Chromium	111	10
Copper	149	14
Mercury	1.06	0.11
Nickel	48.6	2.4
Lead	128	16
Antimony	NA	<0.5
Selenium	NA	<0.5
Thallium	NA	<0.3
Zinc	459	95

[1]PEC = Probable Effect Concentration (McDonald, 2000), [2]ppb = parts per billion (ppm) dry weight basis, [3]NA = None specified

Table 6.53 Special study sediment organics results from VADEQ monitoring station 6AKOX008.11 (July 23, 1997).

Parameter	PEC[1]	VALUE[2]
Total PAH[3]	22,800	2,963.9
High MW[4] PAH	NA	529.6
Low MW PAH	NA	219.0
NAP[5]	561	21.9
NAP 1-Me[6]	NA	51.1
biphenyl	NA	13.5
NAP d-Me[7]	NA	48.6
naphthylene ace~	NA	16.1
NAP t-Me8	NA	43.5
fluorene	536	16.3
PHH[9]	1,170	148.9
ATH[10]	845	15.7
PHH 1-Me	NA	168.2
FTH[11]	2,230	174.9
pyrene	1,520	151.9
ATH benz(a)	1,050	52.7
chrysene	1,290	103.9
FTH benzo(b)	NA	50.2
FTH benzo(k)	NA	24.5
pyrene benzo(e)	NA	39.6
pyrene benzo(a)	1,450	38.2
perylene	NA	17.4
pyrene IND[12]	NA	25.4
ATH db(a,h)[13]	NA	8.0
perylene benzo(ghi)	NA	27.2

[1]PEC = Probable Effect Concentration (McDonald, 2000),[2]ppb = parts per billion (µg/kg or ng/g) dry weight basis, [3]PAH = Polyaromatic hydrocarbon, also polynuclear aromatic hydrocarbons (PNAs), [4]MW = Molecular Weight, [5]NAP = Naphthalene, [6]1-Me Methyl, [7]d-Me 2,6-Dimethyl, [8]t-Me 2,3,5-Trimethyl, [9]PHH = Phenanthrene, [10]ATH = Anthracene, [11]FTH = Fluoranthene, [12]IND = indeno(1,2,3-cd), [13]db(a,h) dibenzo(a,h)

Table 6.54 Special study sediment PCB and pesticide results from three VADEQ monitoring stations on Knox Creek.

Station Date		6AKOX008.11 7/23/97	6AKOX022.00 10/6/03	6AKOX019.30 10/6/03
Parameter	PEC[1]	Value[2]	Value	Value
Total PCB[3]	676	68.02	0.00	99.38
Total BDE[4]	NA	2.28	-	-
OCDD[5]	NA	0.26	-	-
Cl-NAP[6]	NA	1.02	-	-

[1]PEC = Probable Effect Concentration (McDonald, 2000), [2]ppb = parts per billion (ppm) dry weight basis, [3]Total PCB = sum of polychlorinated biphenyl congeners, [4]Total BDE = sum of polybrominated diphenyl ether congeners, [5]OCDD = Octachlorodibenzodioxin, [6]Cl-NAP = 2-Chloronaphthalene

Table 6.55 Sediment metals results from VADEQ monitoring station 6AKOX006.52.

Metal	PEC[1]	Max:	Min:	Mean:	Median:	N[2]
Chromium, mg/kg	111	21	6	12	10.25	10
Copper, mg/kg	149	34	11	19	16.9	11
Lead, mg/kg	128	49	8	17	15.6	11
Nickel, mg/kg	48.6	63	9.42	26	21	11
Zinc, mg/kg	459	180	12	76	59.1	11

[1]PEC = Probable Effect Concentration (McDonald, 2000), [2] N: number of sample measurements.

6.5.1.6 Dissolved Metals Sampling Results – Knox Creek

Dissolved metals were collected at VADEQ monitoring station 6AKOX006.52 on June 22, 2004 and the results are shown in Table 6.56.

Table 6.56 Dissolved metal concentrations at VADEQ monitoring station 6AKOX006.52 on June 22, 2004.

Metal	Value (µg/L)	Acute Water Quality Standard (µg/L)
Aluminum	17.20	N/A
Arsenic	0.18	150
Barium	53.00	N/A
Chromium (III)	0.51	2,937.5
Copper	0.85	32.5
Magnesium	13.10	N/A
Nickel	1.76	314.5
Selenium	0.74	N/A
Zinc	1.33	201.6

N/A = Not Applicable, there is no water quality standard for this metal

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION – KNOX CREEK

7.1 Stressor Identification

Knox Creek begins in eastern Buchanan County and flows northwest to the Virginia/Kentucky state line (river mile 6.52). The impaired section begins at the headwaters and extends to the Virginia/Kentucky state line for a total length of 16.94 stream miles.

For a water quality constituent without an established standard, criteria, or screening value, a 90th percentile screening value was used. The 90th percentile screening values were calculated from 49 monitoring stations in southwest Virginia on third and fourth order streams that were used as benthic reference stations or were otherwise non-impaired based on the most recent benthic sampling results. The 90th percentile screening values were used to develop a list of possible stressors to the benthic community in Knox Creek. For a water quality constituent, or parameter, to be named a probable stressor, additional information was required. Graphs are shown for parameters that exceeded the screening value in more than 10% of the samples collected within the impaired segment or if the parameter had extreme values. Median values are shown if a parameter does not exceed the water quality standard, screening value, 90th percentile screening value, or does not have excessive values. Data for parameters with more than one but less than nine data points can be found summarized in section 6.5.1. The presence of nine values was selected as a cutoff in order to avoid using data from stations that were not sampled during different seasons of the year or different flow regimes in Knox Creek. However, all data was reviewed to ensure consistency with expected value ranges in the stream.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000b) was used to separately identify the most probable stressor(s) for Knox Creek. A list of candidate causes was developed from published literature, VADEQ, and DMME staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Land use data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter.

The results of the stressor analysis for Knox Creek are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors. Non-stressors are listed in Table 7.1.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors. Possible stressors are listed in Table 7.2.
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s). Probable stressors are listed in Table 7.3.

7.2 Non-Stressors

Table 7.1 Non-Stressors in Knox Creek.

Parameter	Location in Document
Low dissolved oxygen	section 7.2.1
Nutrients	section 7.2.2
Toxics (Except sulfate)	section 7.2.3
Metals (Except sediment nickel, iron, total manganese, and total iron)	section 7.2.4
Organic Matter (BOD_5, COD, and TOC)	section 7.2.5

There is always a possibility that conditions in the watershed, available data, and the understanding of the natural processes change more than anticipated by the TMDL. If additional monitoring shows that different most probable stressor(s) exist or water quality target(s) are protective of water quality standards, then the Commonwealth will make use of the option to refine the TMDLs for re-submittal to EPA for approval.

7.2.1 Low Dissolved Oxygen

Dissolved oxygen (DO) concentrations were well above the water quality standard at the VADEQ monitoring stations 6AKOX006.52 and 6AKOX014.17 (Figures 7.1 and 7.2). Low dissolved oxygen is considered a non-stressor. Dissolved oxygen samples were collected just before sunrise (6:00 am) and just after sunrise (7:20 am) on August 5, 2004 to determine if dissolved oxygen concentrations remained above water quality standards during the night. Oxygen demand is highest during the early morning hours during the summer months and this can be a time when water quality standard violations occur. The measurements were 6.98 and 7.02 mg/L respectively indicating that dissolved oxygen concentrations remain well above the water quality standards even during the critical time periods just before daylight.

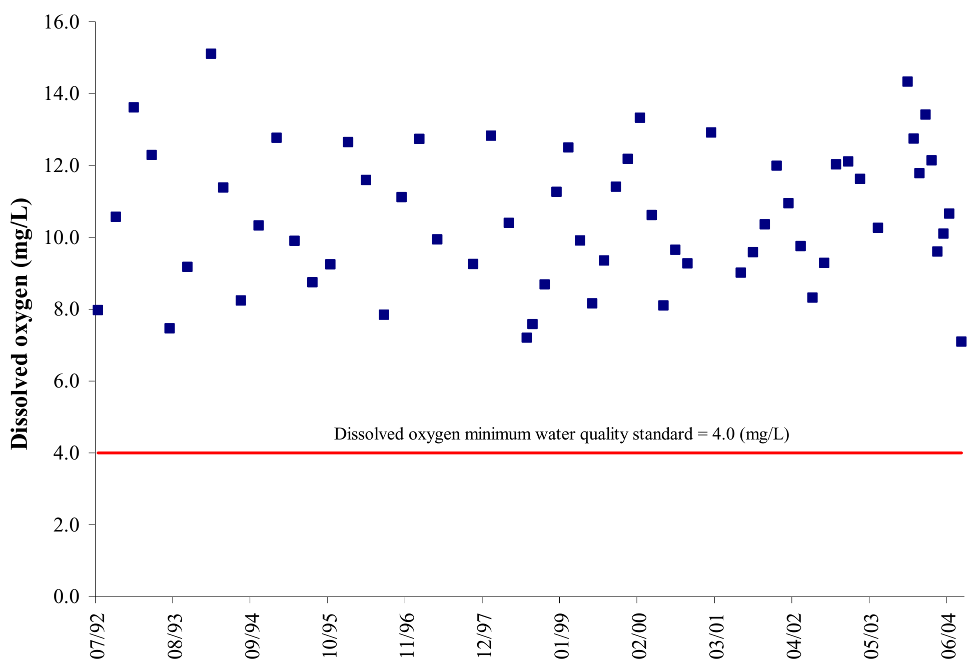

Figure 7.1 Dissolved oxygen concentrations at VADEQ monitoring station 6AKOX006.52.

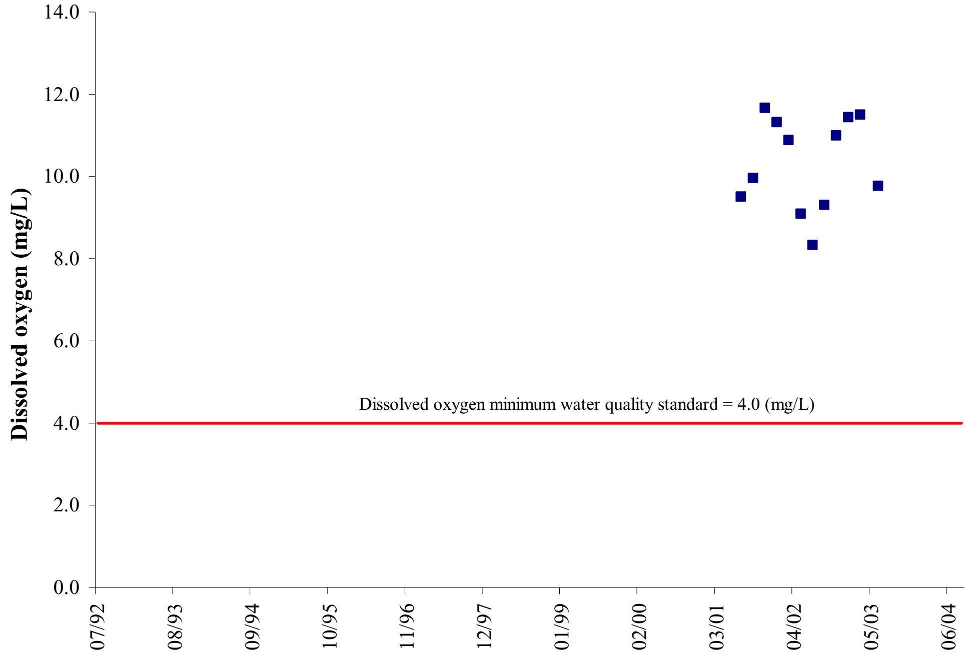

Figure 7.2 Dissolved oxygen concentrations at VADEQ monitoring station 6AKOX014.17.

7.2.2 Nutrients

Total Phosphorus (TP) concentrations were generally very low at both VADEQ monitoring stations. The VADEQ screening value of 0.2 mg/L was exceeded once at each station (Figures 7.3 and 7.4). Nitrate nitrogen concentrations were also low with occasional spikes above 1.0 mg/L (Figures 7.5 and 7.6). Nutrients are considered non-stressors.

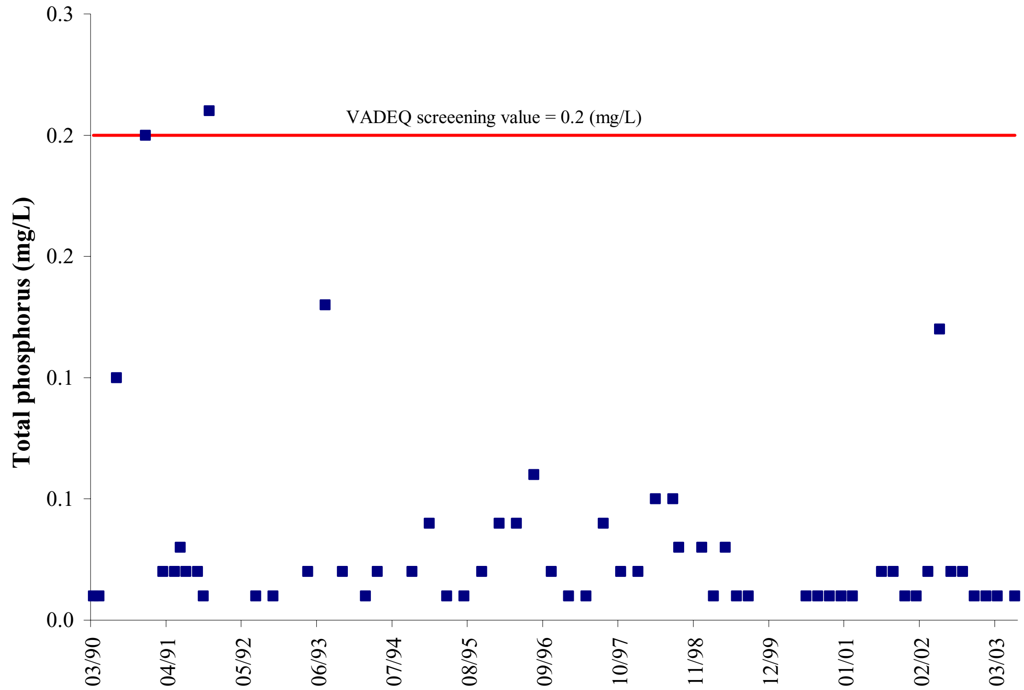

Figure 7.3 Total phosphorus concentrations at VADEQ station 6AKOX006.52.

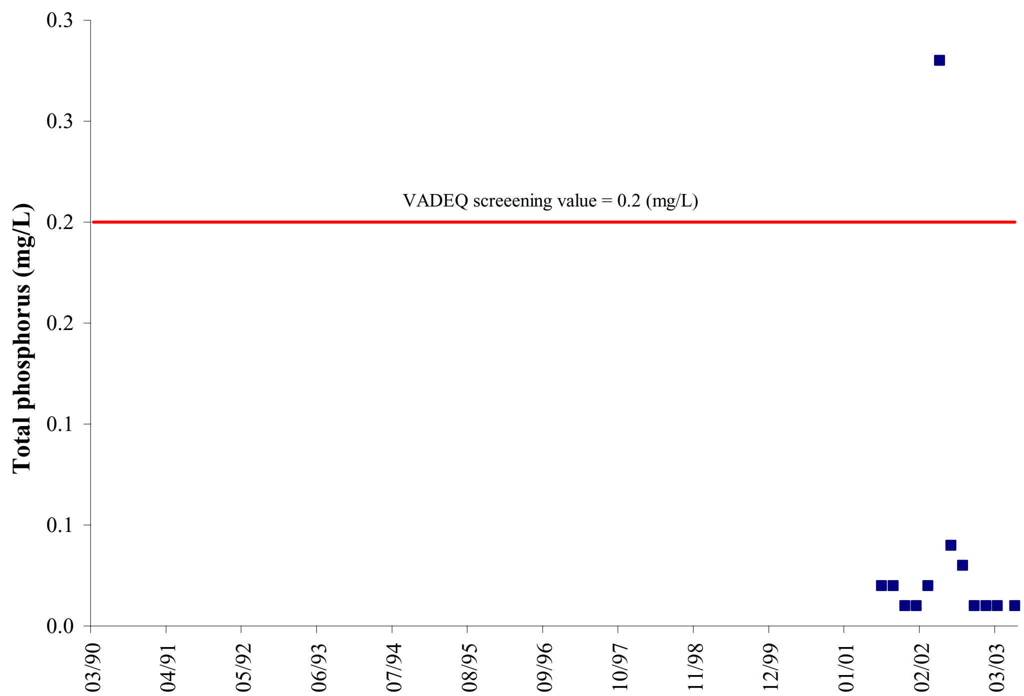

Figure 7.4 Total phosphorus concentrations at VADEQ station 6AKOX014.17.

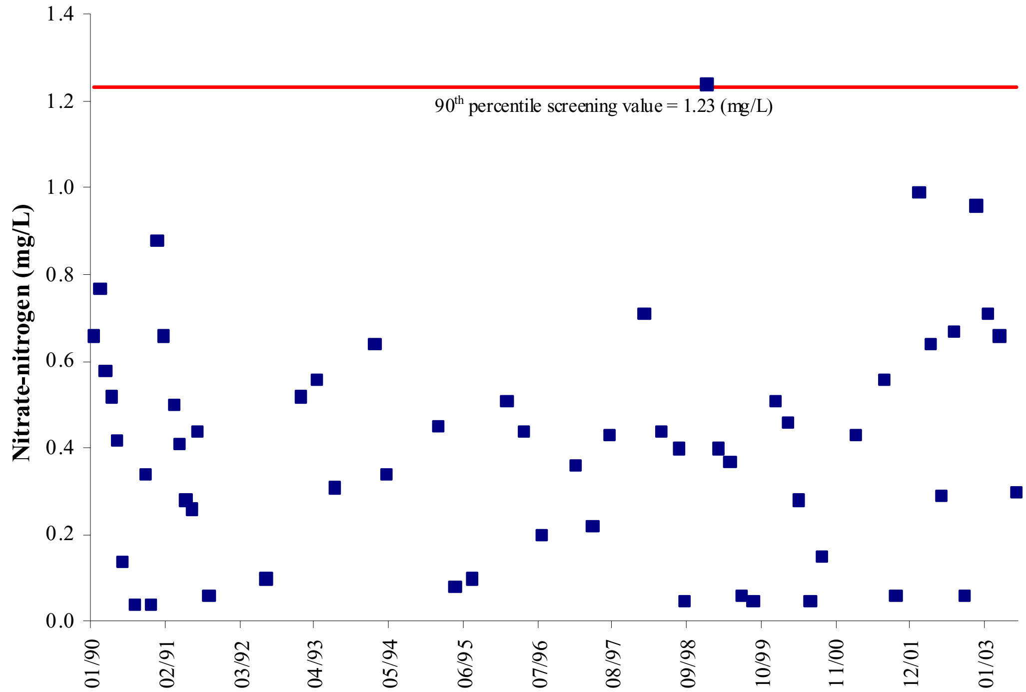

Figure 7.5 Nitrate-nitrogen concentrations at VADEQ station 6AKOX006.52.

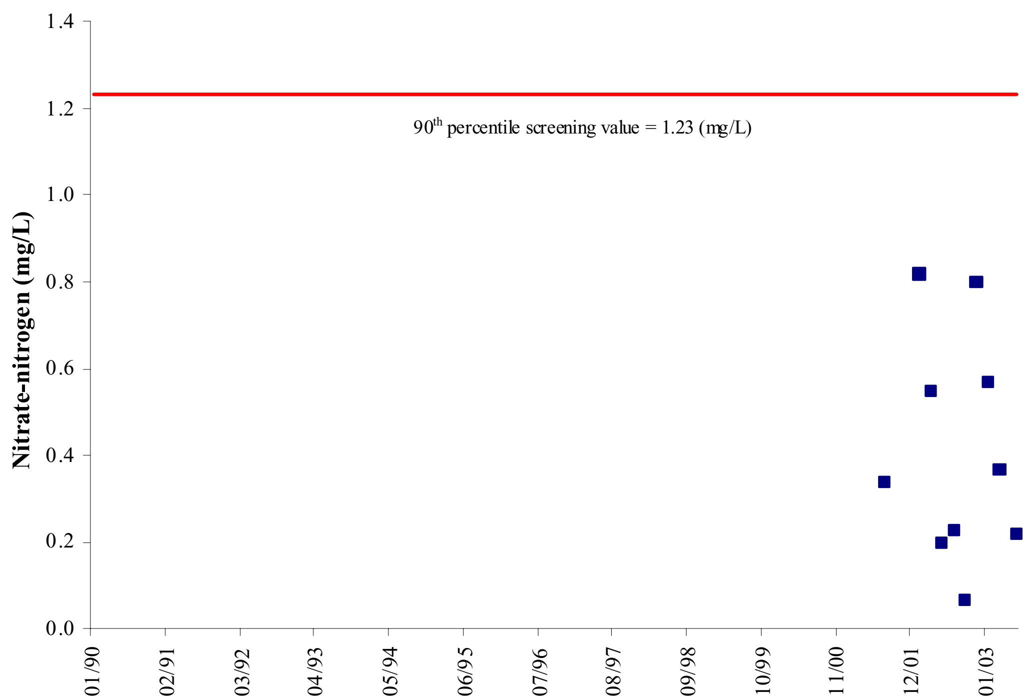

Figure 7.6 Nitrate-nitrogen concentrations at VADEQ station 6AKOX014.17.

7.2.3 Toxics

Only six ammonia (NH_3/NH_4) samples were collected at VADEQ 6AKOX006.52 and one sample at 6AKOX014.17. Total ammonia concentrations were below water quality standards at both VADEQ monitoring stations.

Fish tissue and sediment PCBs, organics, and pesticides were collected at VADEQ station 6AKOX008.11 on July 23, 1997. Subsequent PCB sampling was done on October 6, 2003 at VADEQ stations 6AKOX022.00 and 6AKOX019.30. PCB concentrations in fish tissue exceeded the VDH action level of 50 ppb (parts per billion) at all three monitoring stations (Table 6.50). The VDH has issued a fish consumption ban for the entire Knox Creek watershed. However, all sediment values (even total PCBs) at the three monitoring stations were below the established Consensus Probable Effect Concentrations (PEC) values (MacDonald et al., 2000).

7.2.4 Metals

This section discusses VADEQ water quality monitoring for metals dissolved in the water column, metals in the sediment, and metals in fish tissue. Water column dissolved metals were sampled at VADEQ station 6AKOX006.52 on 6/22/2004 and all results were below the appropriate water quality standard (Table 6.56). Not all of the metals listed have established VADEQ or USEPA water quality standards.

All sediment metal values were below the PEC values with the exception of nickel. Table 6.55 shows the sediment metals compared to the PEC value for chromium, copper, lead, nickel and zinc. Based on the results of the dissolved metals, sediment metals, and fish tissue metals data, metals are considered non-stressors with the exceptions of sediment nickel, sediment iron, total manganese, and total iron (section 7.3.3).

7.2.5 Organic matter (BOD_5, TOC & COD)

Several different parameters were used to evaluate the impact of organic matter in the stream on the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5), total organic carbon (TOC), and chemical oxygen demand (COD) provide an indication of how much dissolved organic matter is present (organic solids are discussed in section 7.3.3). Concentrations of BOD_5, TOC, and COD did not exceed the 90th percentile screening concentration in more than 10% of the samples collected (Figures 7.7 through 7.9). There was one extreme spike in COD in July 1991 (517 mg/L). Therefore, these forms of organic matter are considered non-stressors.

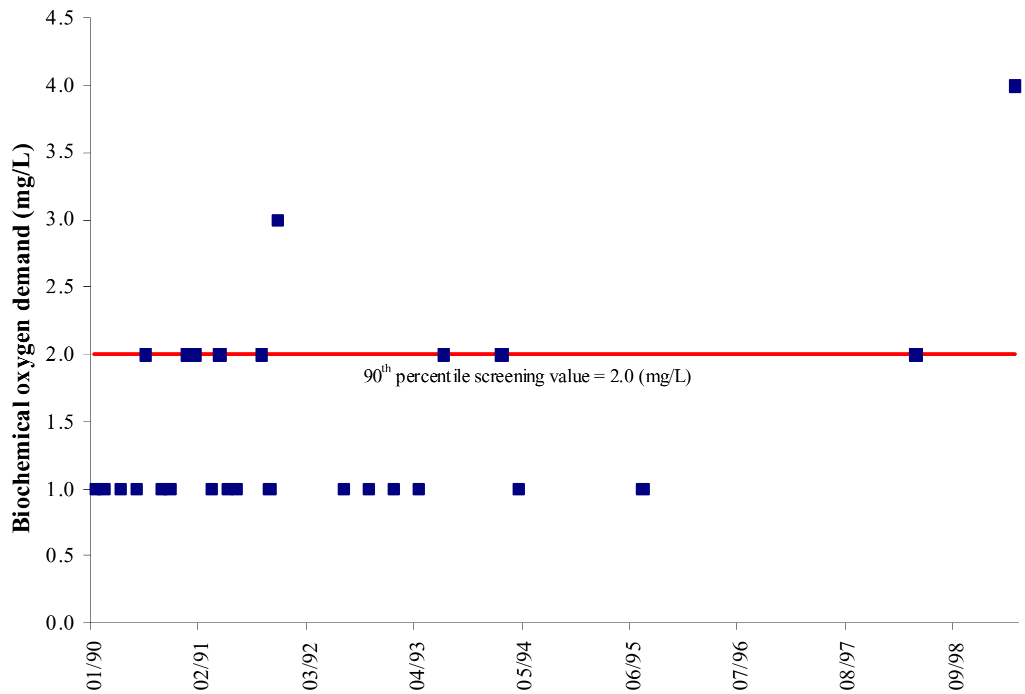

Figure 7.7 BOD_5 concentrations at VADEQ station 6AKOX006.52.

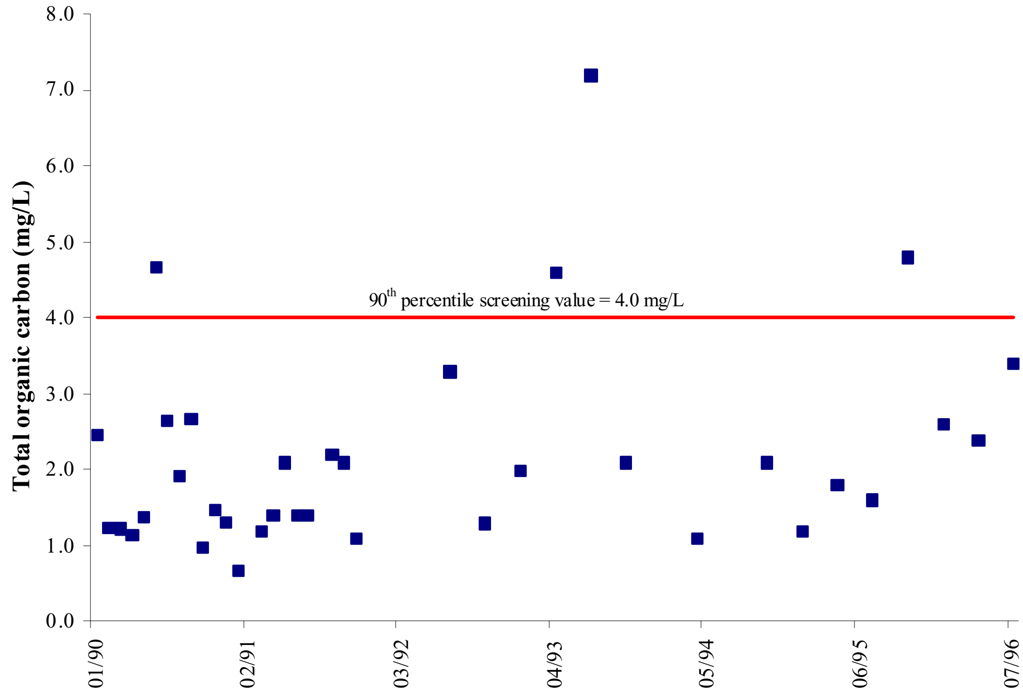

Figure 7.8 TOC concentrations at VADEQ station 6AKOX006.52.

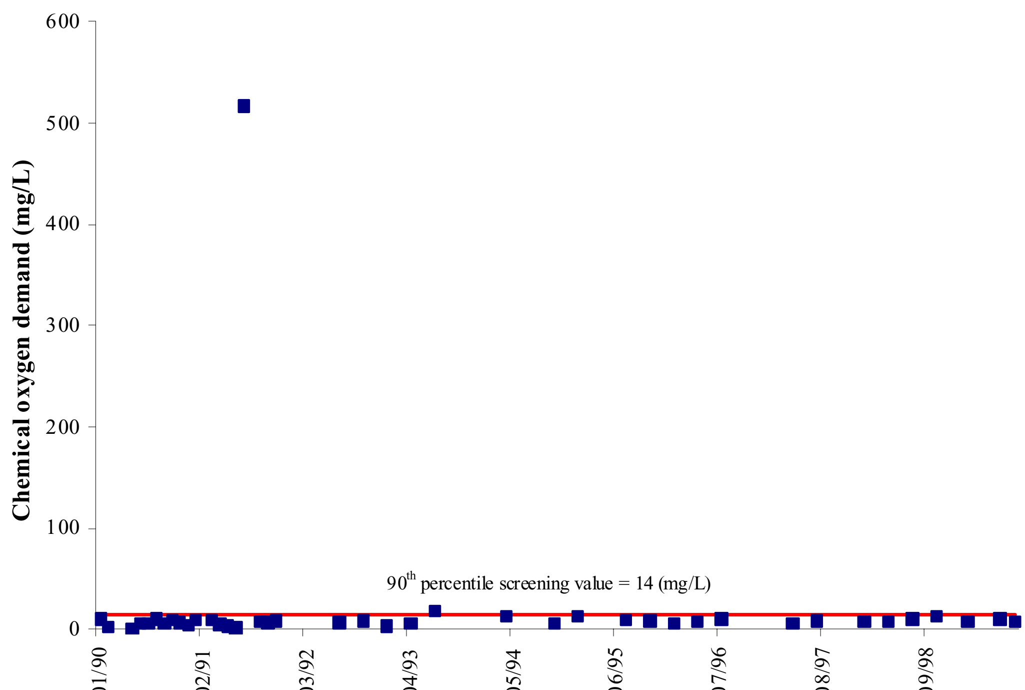

Figure 7.9 COD concentrations at VADEQ station 6AKOX006.52.

7.3 Possible Stressors

Table 7.2 Possible Stressors in Knox Creek.

Parameter	Location in Document
Temperature	section 7.3.1
pH	section 7.3.2
Organic matter (Total organic solids and total organic suspended solids)	section 7.3.3
Sediment nickel, iron, total manganese, and total iron	section 7.3.4
Sulfate	section 7.3.5
Sediment	section 7.3.6

7.3.1 Temperature

The maximum temperature standard for Knox Creek is 31.0°C. The maximum temperature recorded at the two VADEQ monitoring stations on Knox Creek was 28.0°C (Figures 7.10 and 7.11). The maximum temperature recorded at the DMME MPIDs on Knox Creek was 33.0°C, at MPID 6020033 on July 10, 1997, and 32.0°C, at MPID 6084668 on July 28, 1997 (Figures 7.12 and 7.13). Median temperature measurements for all monitoring sites on Knox Creek are shown in Figure 7.14. Temperature standard violations are neither persistent nor extreme and therefore temperature is considered a possible stressor.

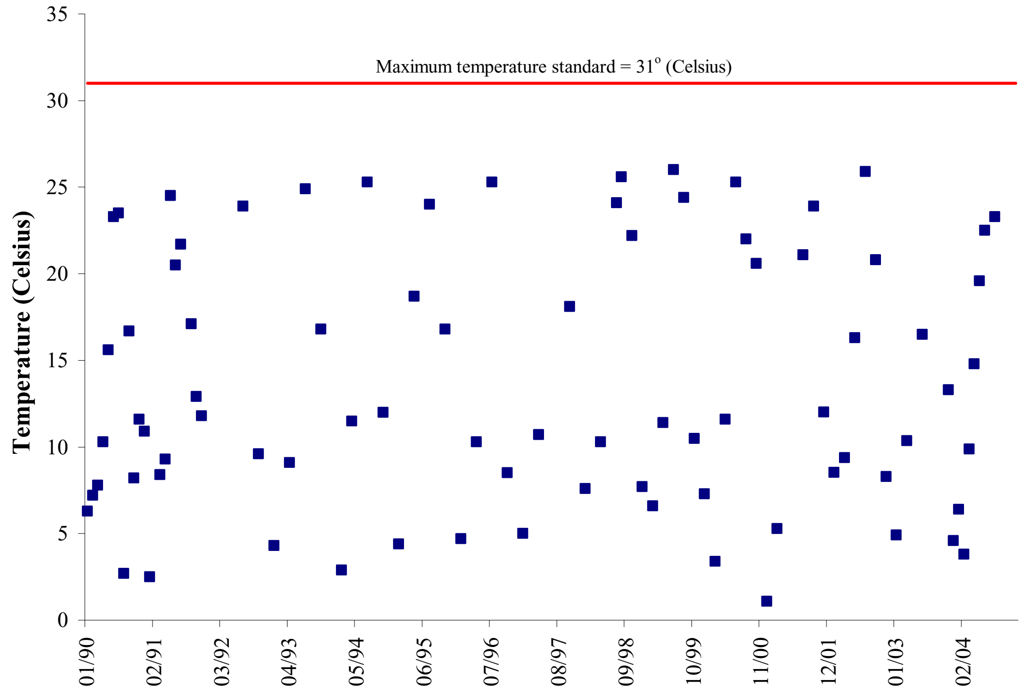

Figure 7.10 Temperature measurements at VADEQ station 6AKOX006.52.

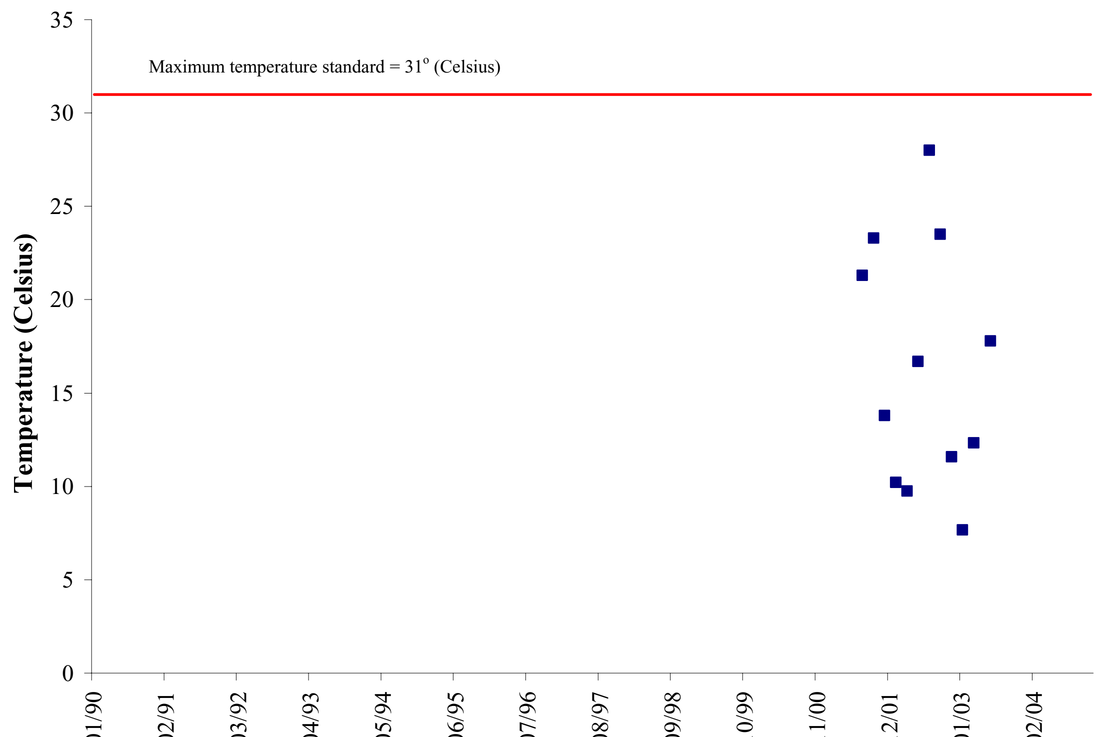

Figure 7.11 Temperature measurements at VADEQ station 6AKOX014.17.

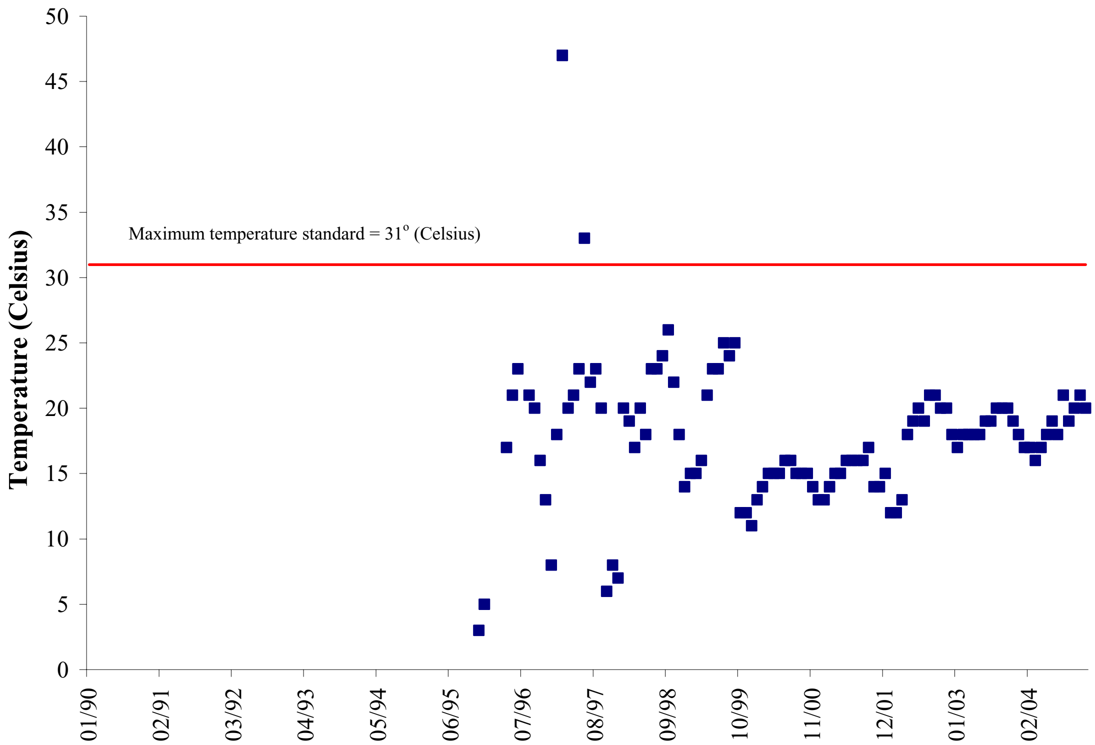

Figure 7.12 Temperature measurements at DMME MPID 6020033.

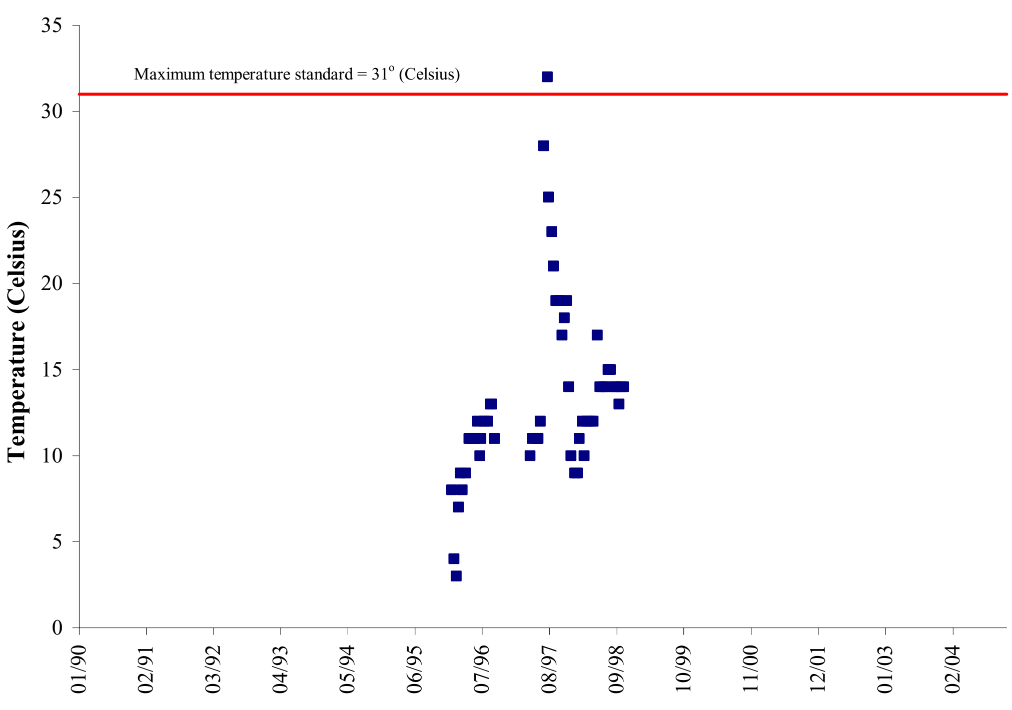

Figure 7.13 Temperature measurements at DMME MPID 6084668.

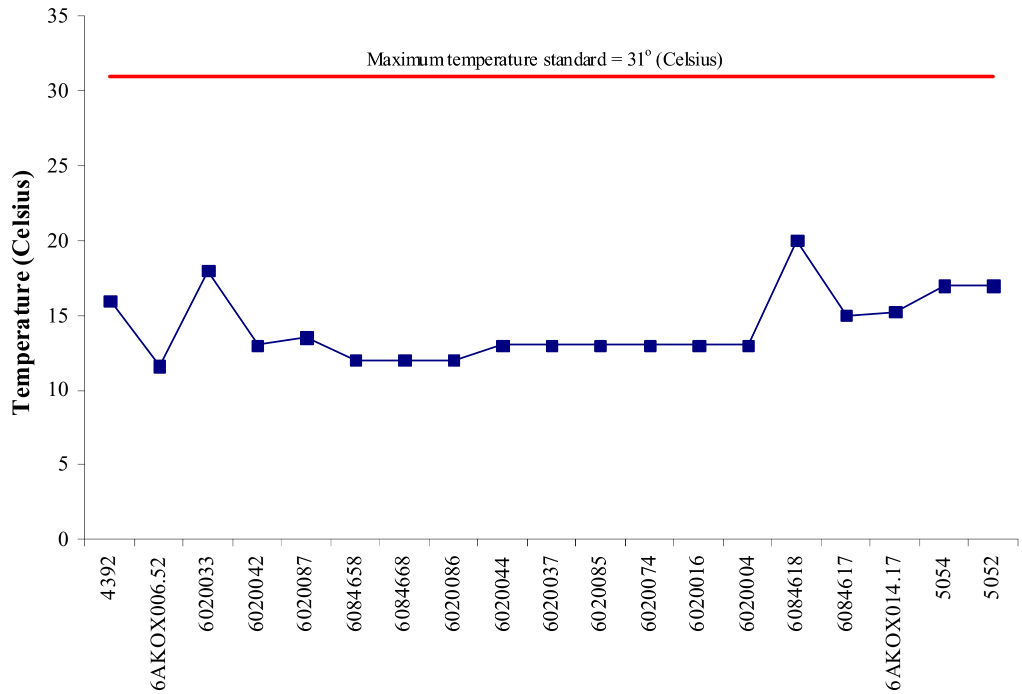

Figure 7.14 Median temperature measurements at DMME MPIDs on Knox Creek.

7.3.2 pH

Field pH values were within water quality standards at both VADEQ monitoring stations on Knox Creek (Figures 7.15 and 7.16). A single field pH value (5.8 std units) at DMME MPID 5054 was below the minimum water quality standard (WQS) of 6.0 (std units) (Figure 7.17). In addition, a single field pH value (4.65 std units) was below the minimum WQS at MPID 6084658 in November 2002 (Figure 7.18). Medians for all monitoring sites on Knox Creek are shown in Figure 7.19. Because low pH values have not been persistent or chronic in Knox Creek, low pH is considered a possible stressor.

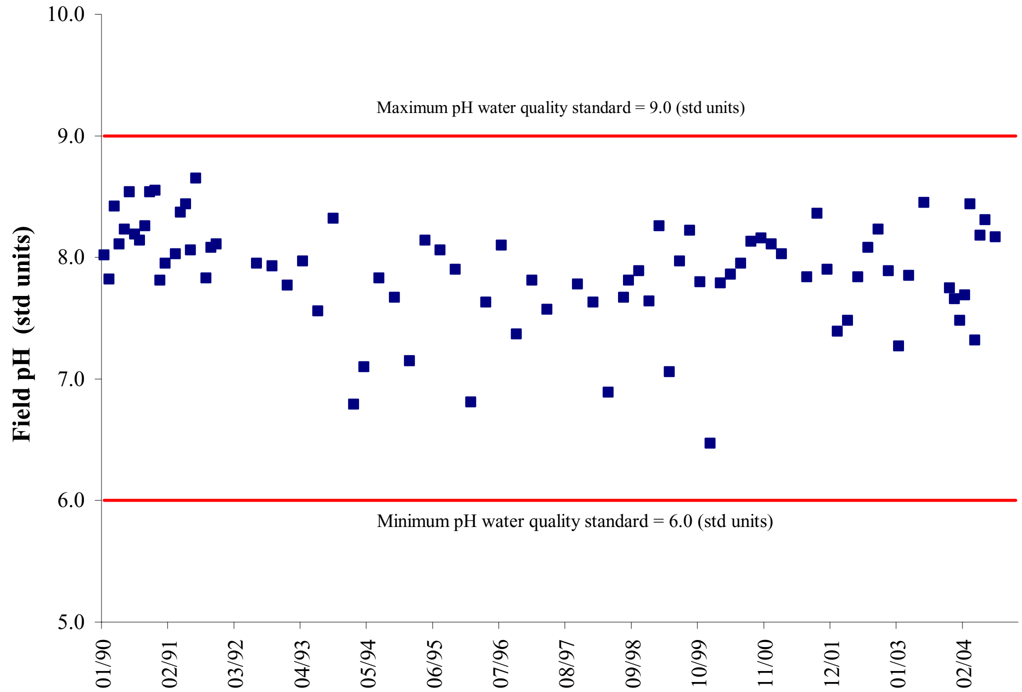

Figure 7.15 Field pH values at VADEQ monitoring station 6AKOX006.52.

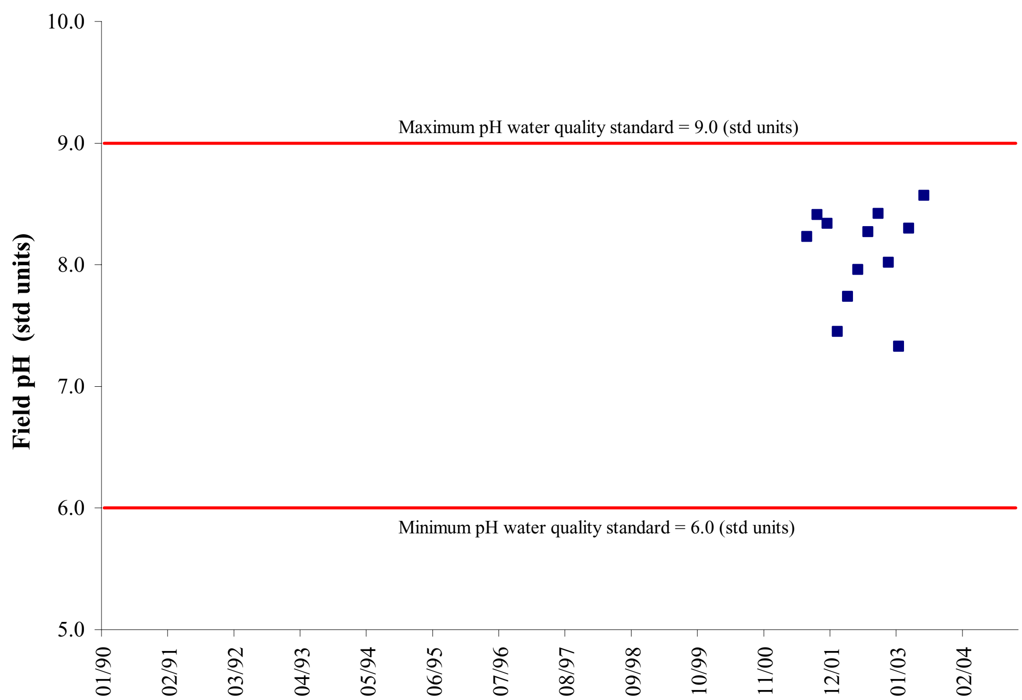

Figure 7.16 Field pH values at VADEQ monitoring station 6AKOX014.17.

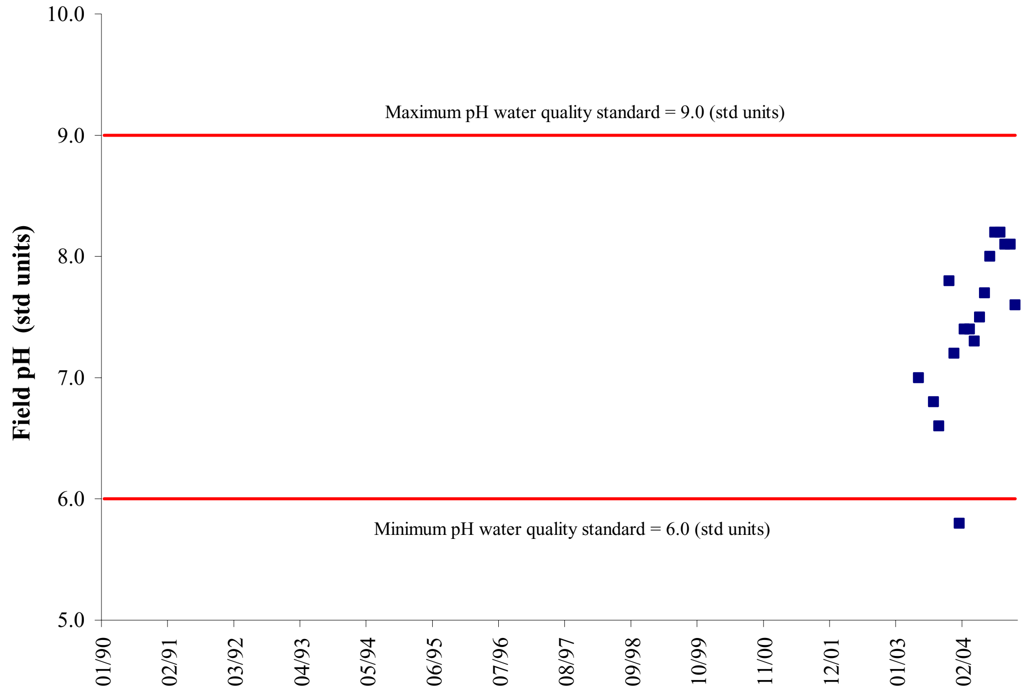

Figure 7.17 Field pH values at DMME MPID 5054.

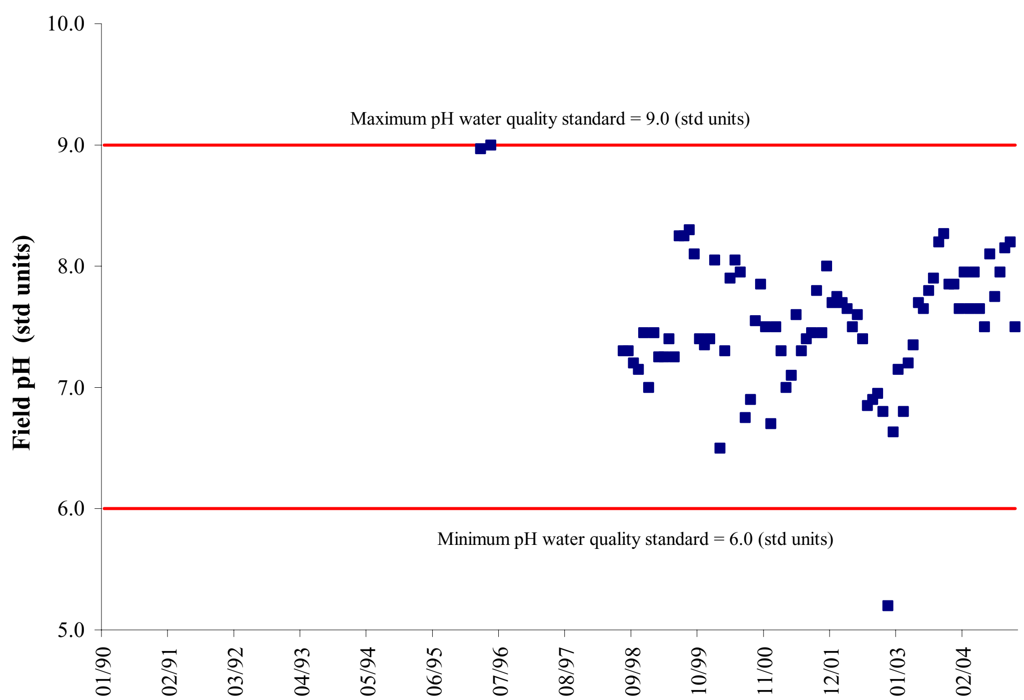

Figure 7.18 Field pH values at DMME MPID 6084658.

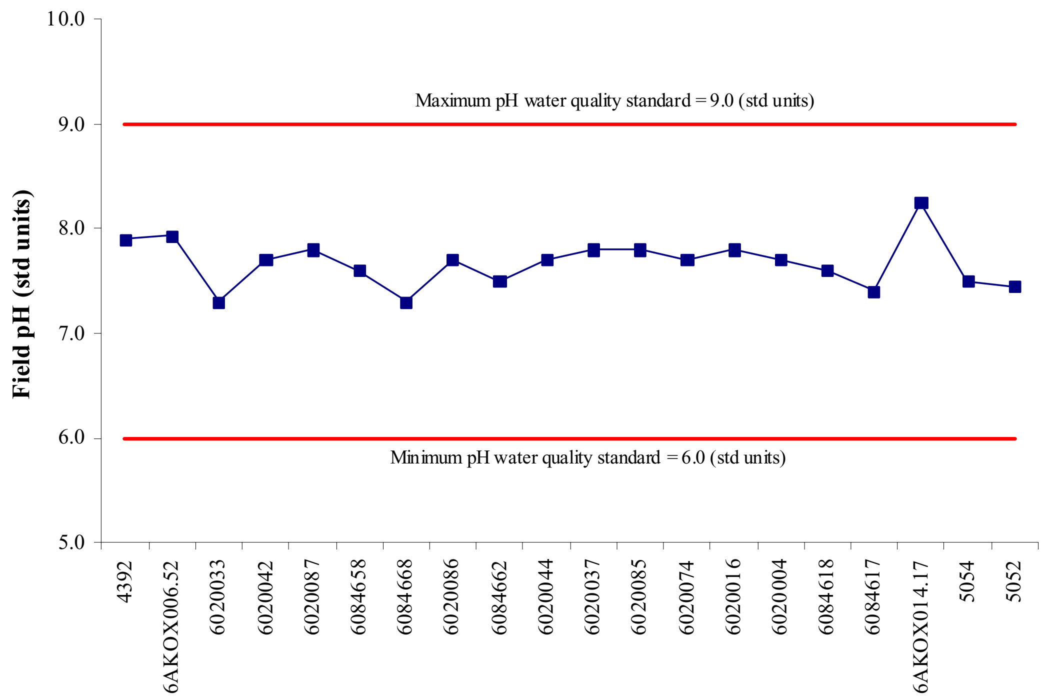

Figure 7.19 Median field pH values in Knox Creek.

7.3.3 Organic matter (Total organic solids and total organic suspended solids)

Total organic solids (also called total volatile solids, TVS) provide an indication of dissolved and suspended organic matter. TVS concentrations exceeded the 90th percentile screening concentration (63 mg/L) in 29 of the 72 samples collected at VADEQ station 6AKOX006.52. Total organic suspended solids (also called total volatile suspended solids, TVSS) provide an indication of particulate organic matter in a stream. TVSS also exceeded the 90th percentile concentration in four of 32 samples at VADEQ 6AKOX006.52.

Figures 7.20 and 7.21 show the concentrations for these two parameters at VADEQ 6AKOX006.52. The assemblage for benthic station 6AKOX008.51 from the VADEQ Ecological Data Application System (EDAS) database was examined, and hydropsychidae (netspinning caddisflies) were not found to be the dominant family (14%). According to Voshell (2002), "If common netspinners account for the majority of the community that is a reliable indicator of organic or nutrient pollution." Therefore, organic solids are considered a possible stressor.

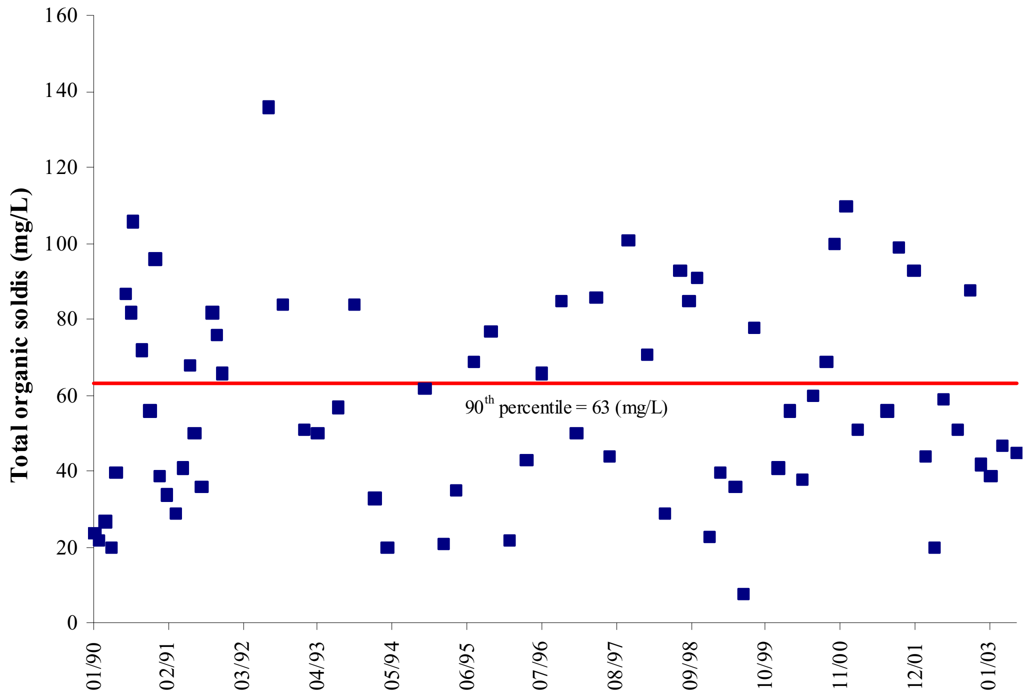

Figure 7.20 Total organic solids concentrations at VADEQ station 6AKOX006.52.

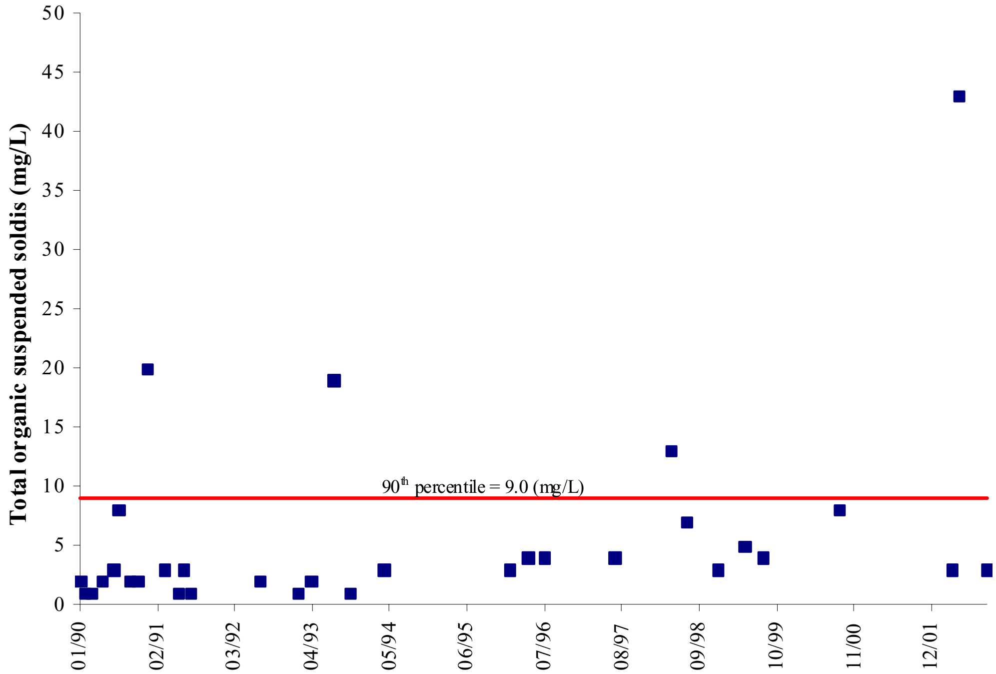

Figure 7.21 Total organic suspended solids concentrations at VADEQ station 6AKOX006.52.

7.3.4 Metals (sediment nickel, iron, total manganese, and total iron)

One sediment nickel value out of 11 samples exceeded the PEC value (48.6 mg/kg) at VADEQ monitoring station 6AKOX006.52. The exceedance occurred in July 1993. There have been seven sampling events since 1993 (1994 through 1999, and 2004) and the subsequent values have been well below the PEC value (Figure 7.22). In the absence of sediment toxicity testing for nickel, and the fact that recent values have been below the PEC value, nickel is considered a possible stressor.

One sediment iron value exceeded the 90th percentile screening value (26,412 mg/kg) in July of 1996. Four values have been collected since and they were below the screening value (Figure 7.23). There is not a PEC value or other literature value that indicates at what levels iron in sediment may be harmful to aquatic life, therefore sediment iron is considered a possible stressor.

The minimum detection concentration for total manganese is 0.10 mg/L and the 90th percentile screening value is 0.060 mg/L. Knox Creek exceeded the minimum detection level in more than 10% of the samples collected at 10 DMME MPID monitoring sites. Site 6084617 had a maximum concentration of 9.2 mg/L and site 6084618 had a maximum concentration of 2.2 mg/L (Figures 7.24 through 7.33). Median total manganese concentrations at DMME MPID sites are shown in Figure 7.34. There is little research available indicating at what levels manganese concentrations in the water column may be harmful to aquatic life. In addition, these results are for total manganese not dissolved manganese. It is the dissolved fraction of metals concentrations that can be toxic to aquatic life.

The state of West Virginia has a water quality standard of 1.5 mg/L for total iron. Three DMME MPIDs exceeded 1.5 mg/L in more than 10% of the samples collected (Figures 7.35 through 7.37). Median total iron concentrations can be found in Figure 7.38. No studies were found indicating that total iron and/or total manganese could impair a benthic community at the concentrations found in Knox Creek. Therefore total iron and manganese are considered possible stressors.

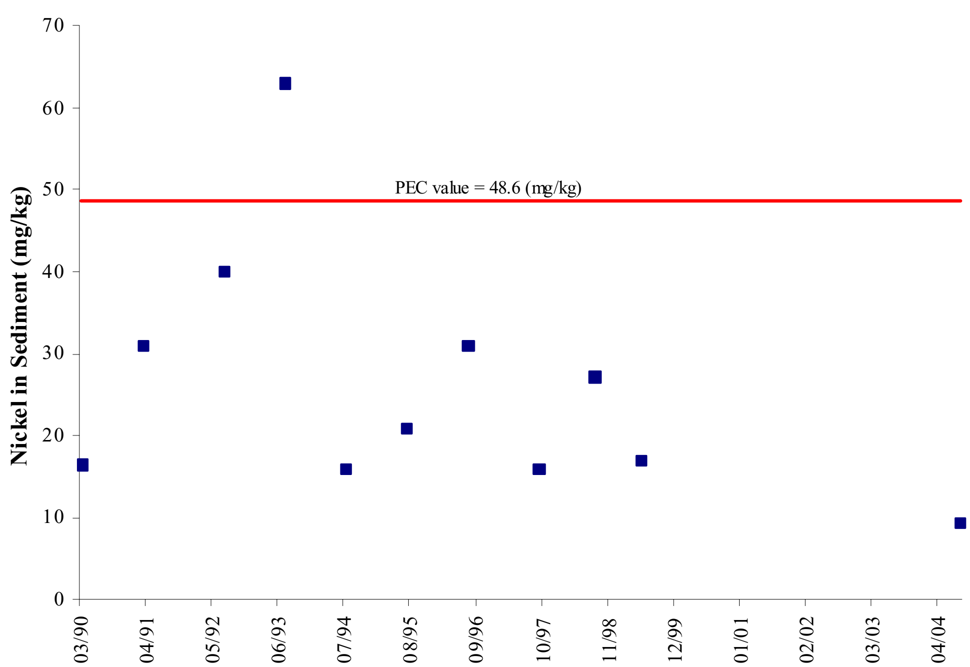

Figure 7.22 Sediment nickel values at VADEQ monitoring station 6AKOX006.52.

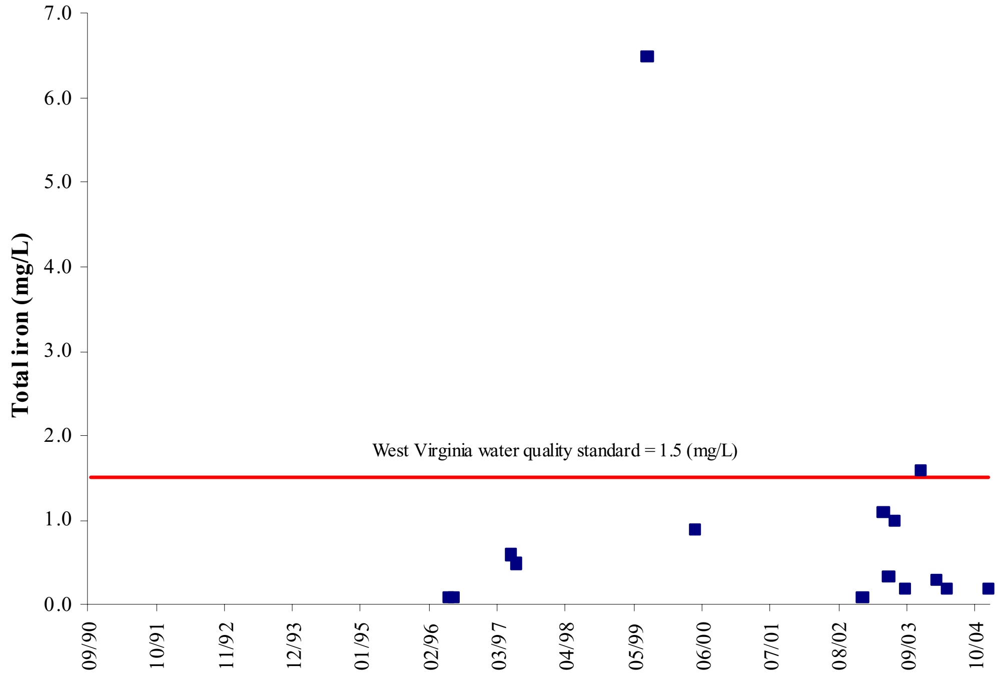

Figure 7.23 Sediment iron values at VADEQ monitoring station 6AKOX006.52.

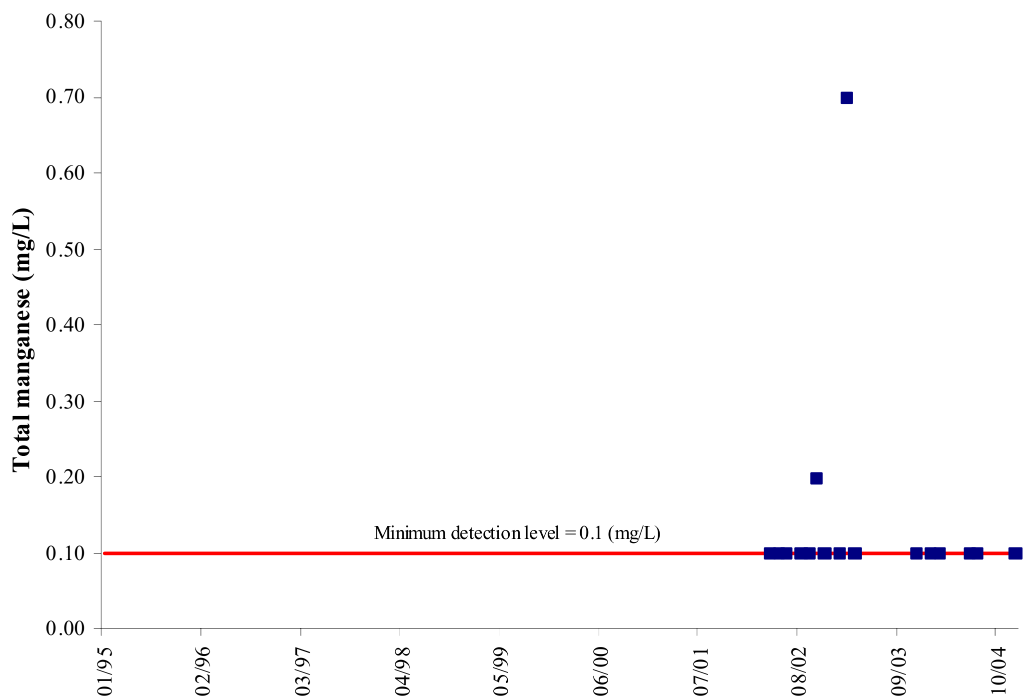

Figure 7.24 Total manganese concentrations at DMME MPID 4392.

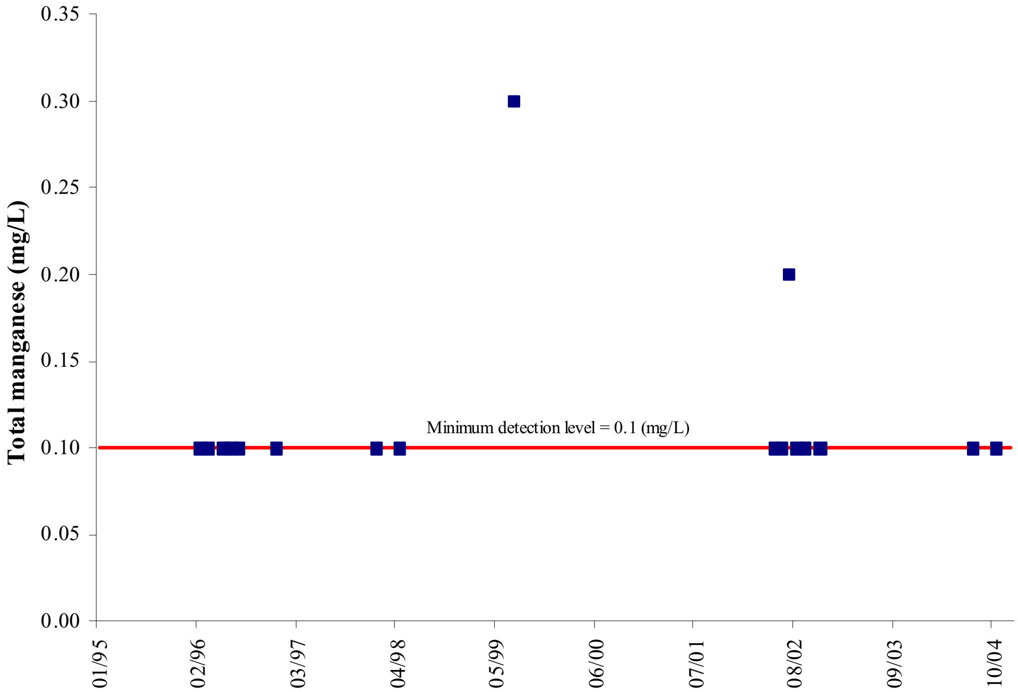

Figure 7.25 Total manganese concentrations at DMME MPID 6020004.

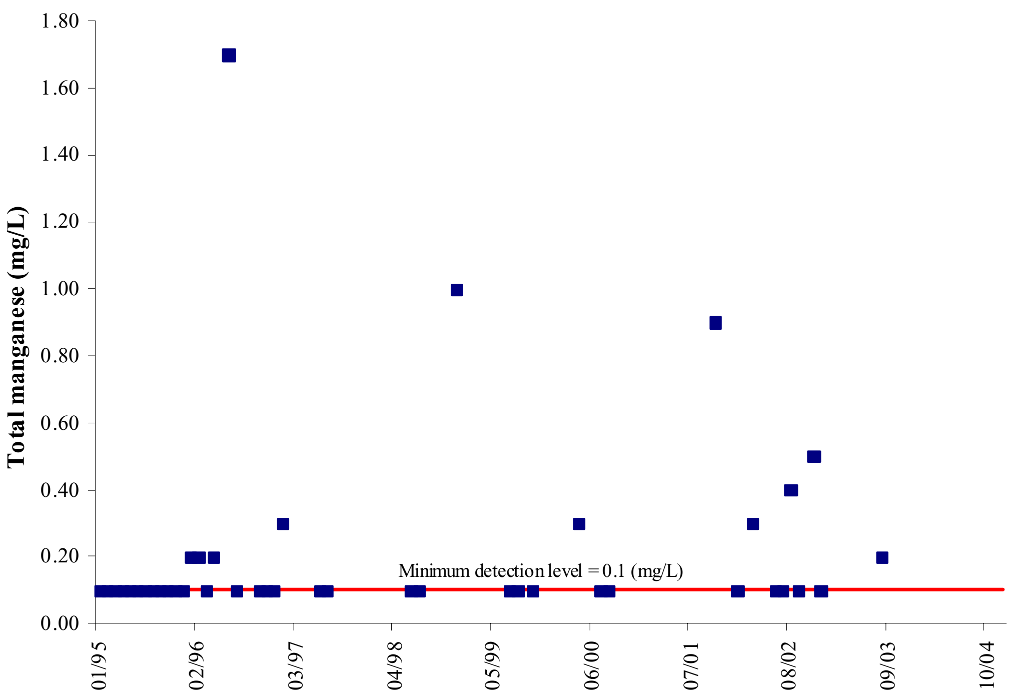

Figure 7.26 Total manganese concentrations at DMME MPID 6020016.

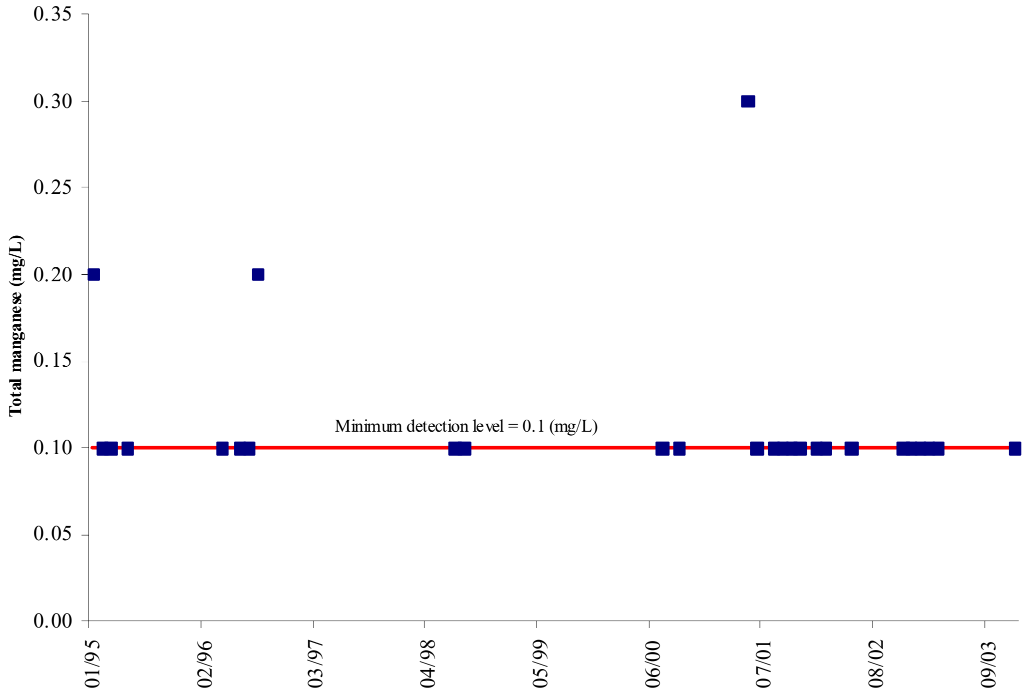

Figure 7.27 Total manganese concentrations at DMME MPID 6020037.

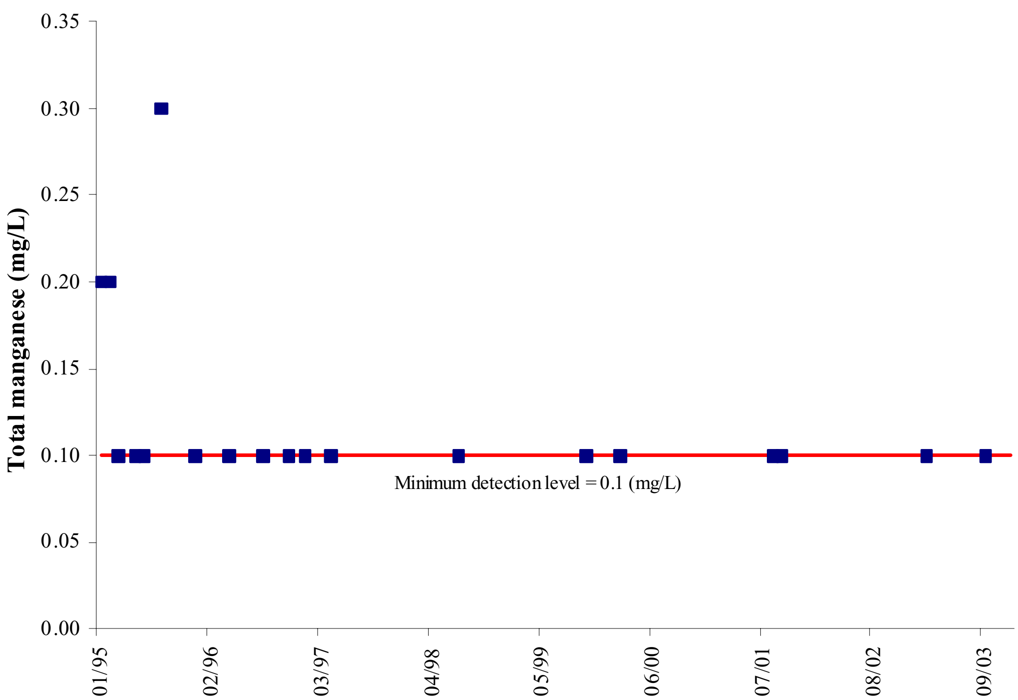

Figure 7.28 Total manganese concentrations at DMME MPID 6020074.

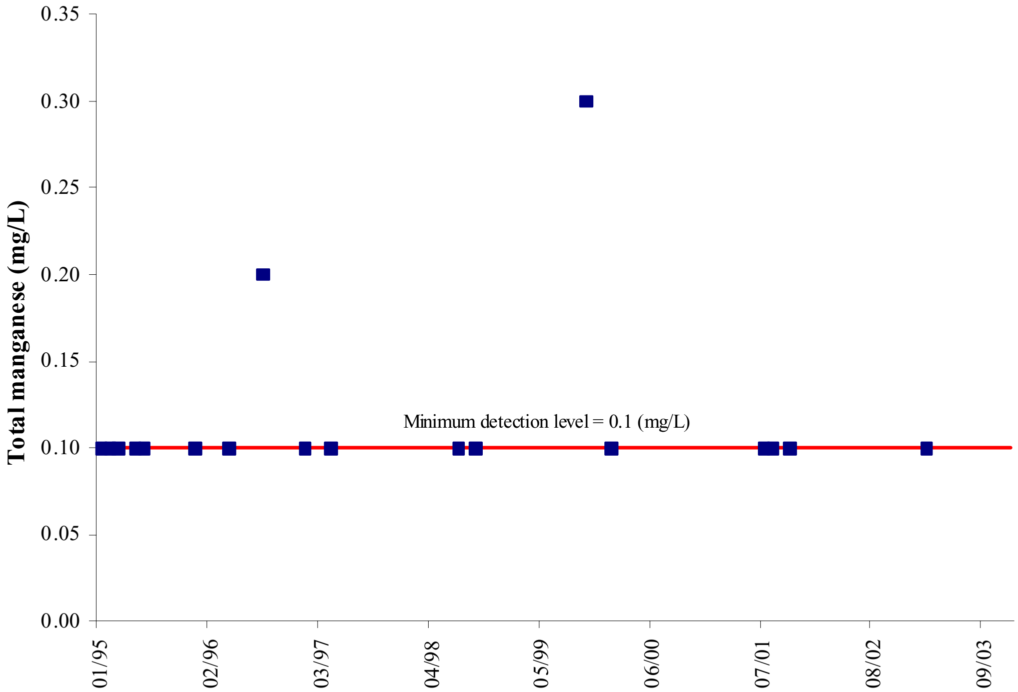

Figure 7.29 Total manganese concentrations at DMME MPID 604685.

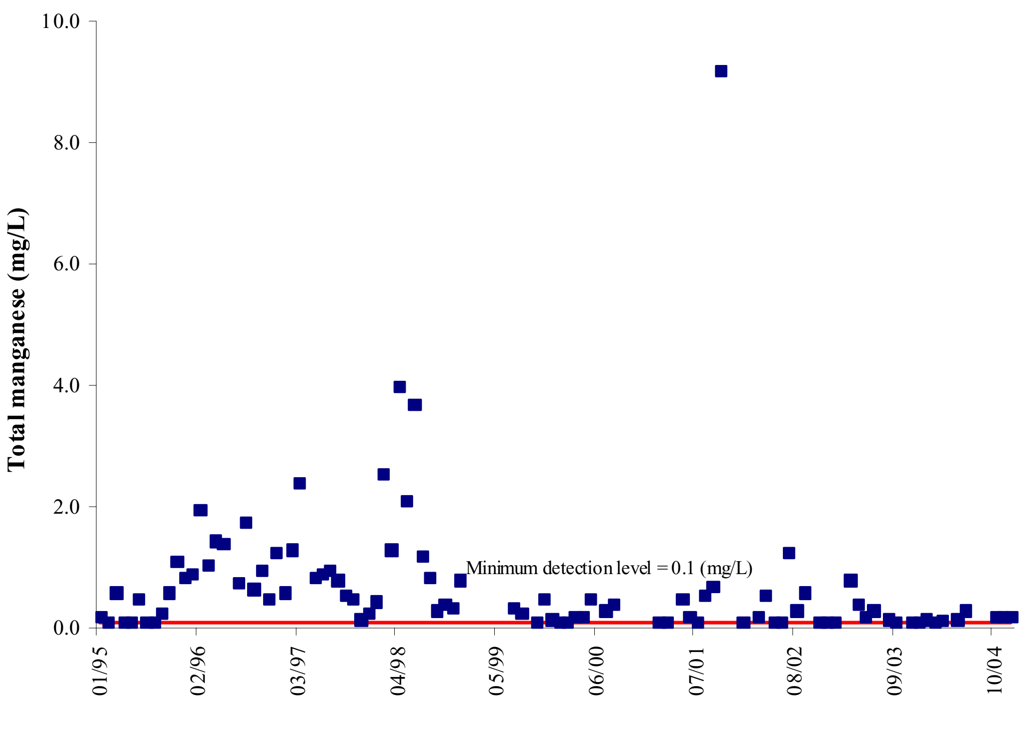

Figure 7.30 Total manganese concentrations at DMME MPID 6024617.

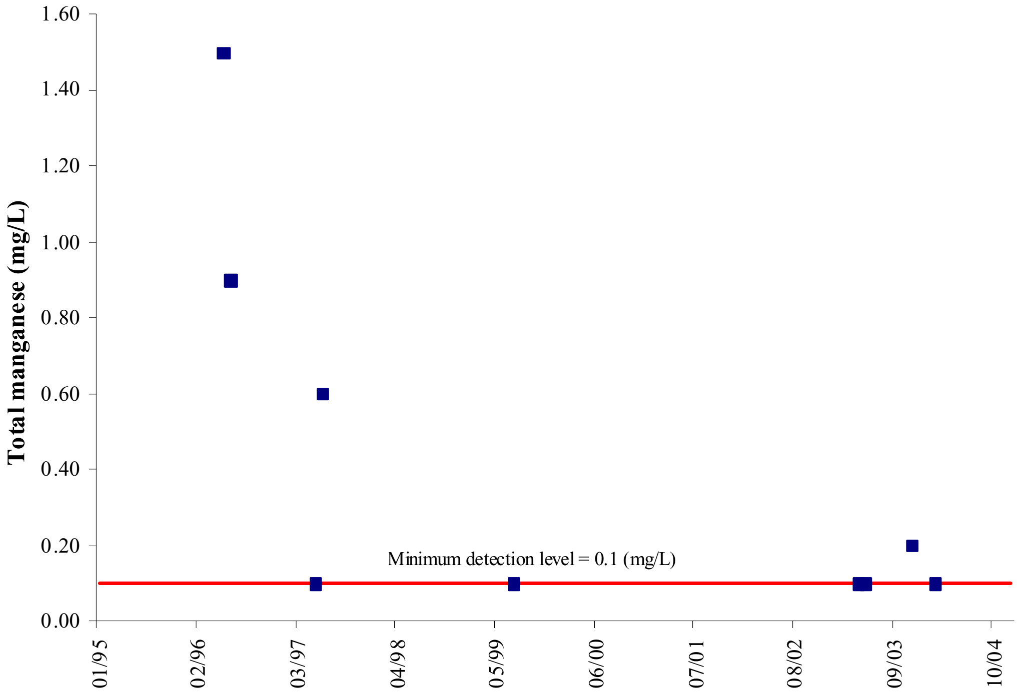

Figure 7.31 Total manganese concentrations at DMME MPID 6084618.

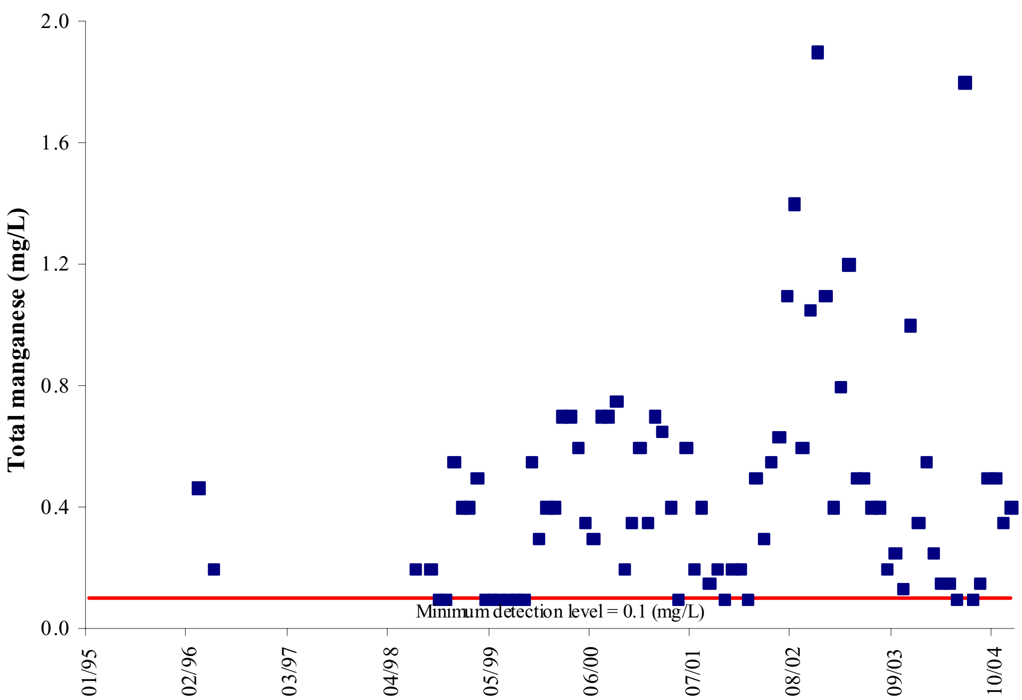

Figure 7.32 Total manganese concentrations at DMME MPID 6024658.

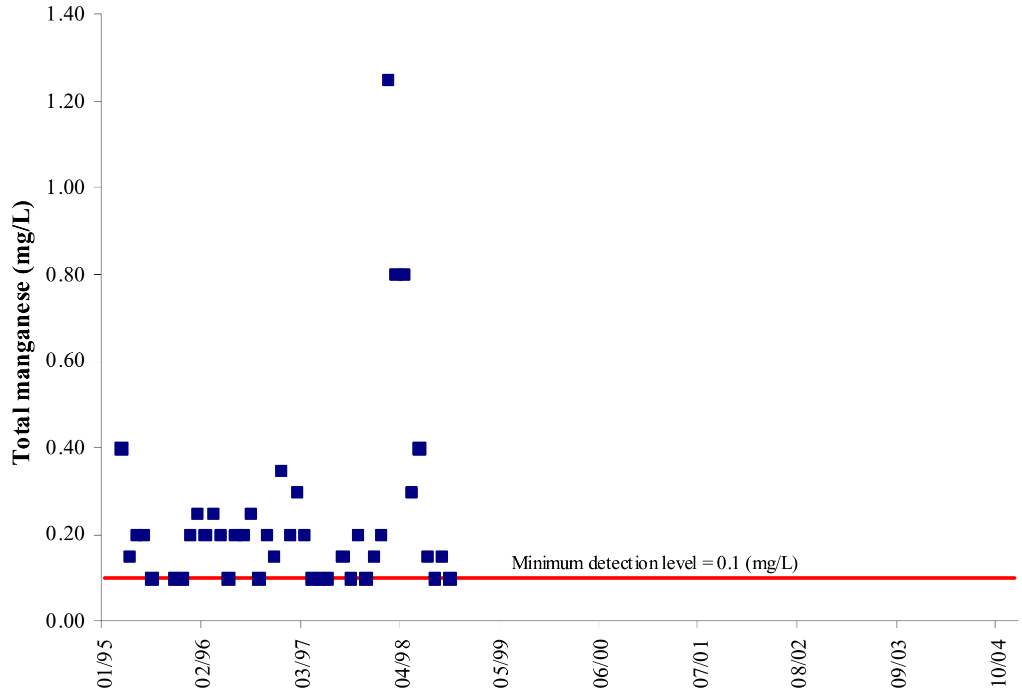

Figure 7.33 Total manganese concentrations at DMME MPID 6024668.

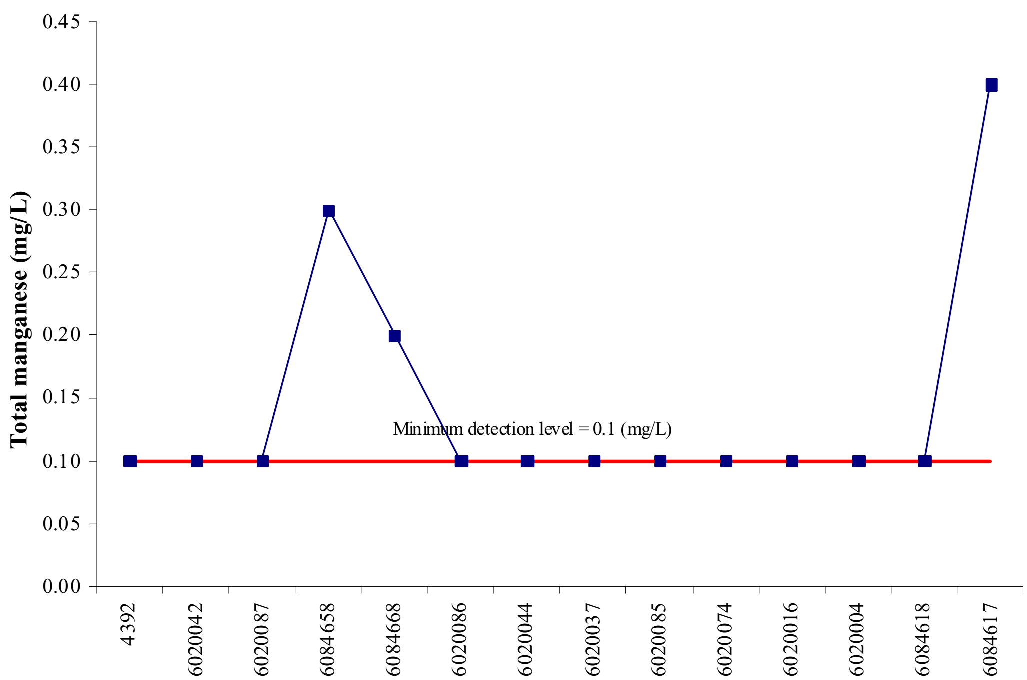

Figure 7.34 Median total manganese concentrations at DMME MPID sites in Knox Creek.

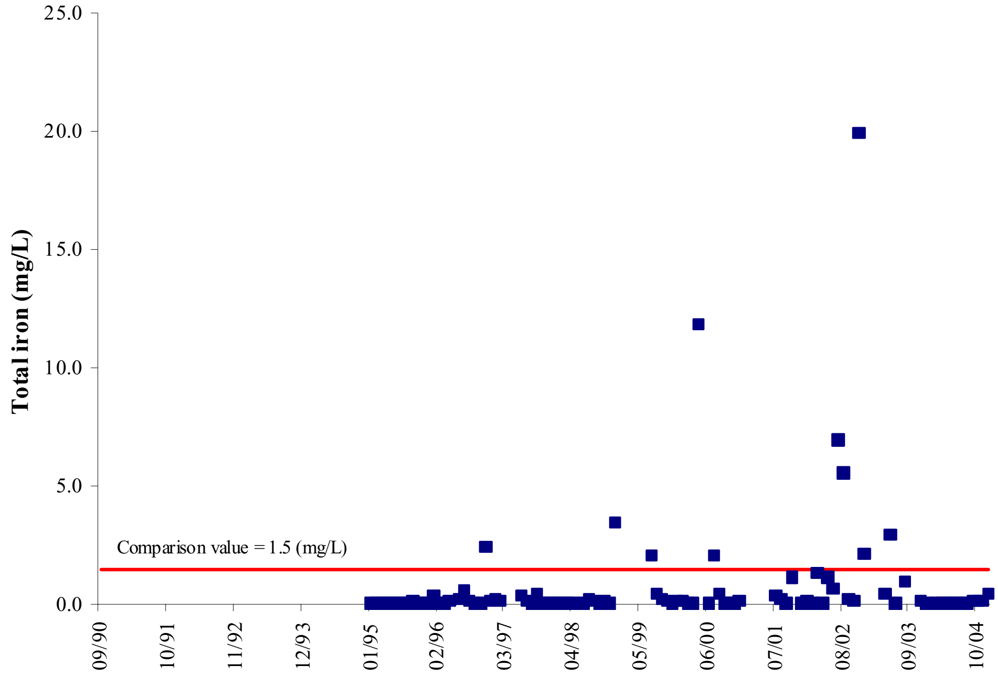

Figure 7.35 Total iron concentrations at DMME MPID 6020016.

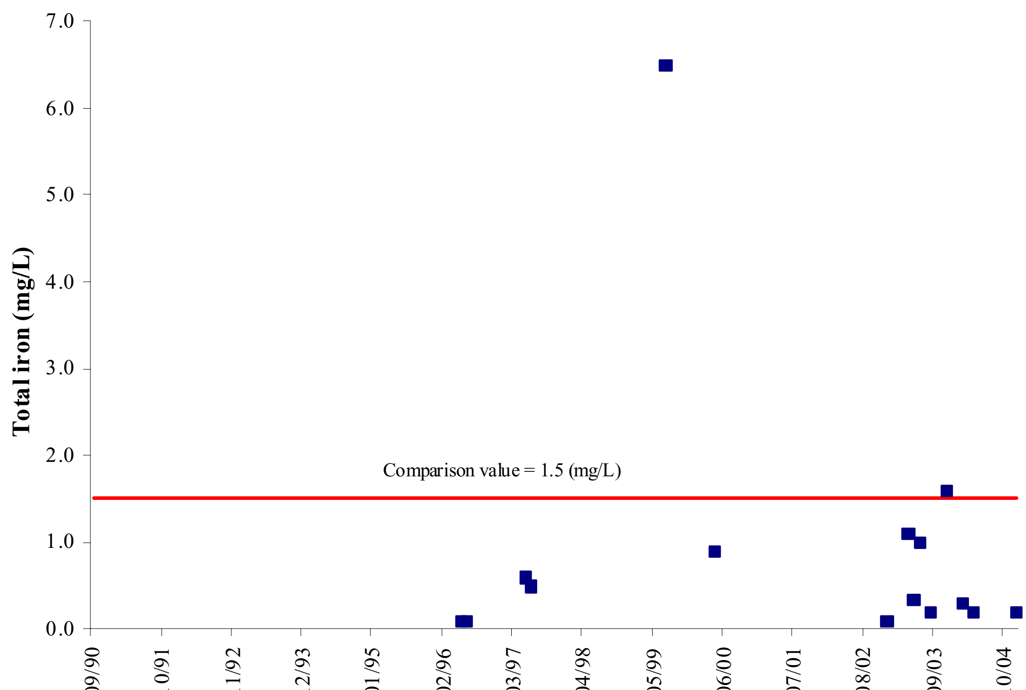

Figure 7.36 Total iron concentrations at DMME MPID 6084618.

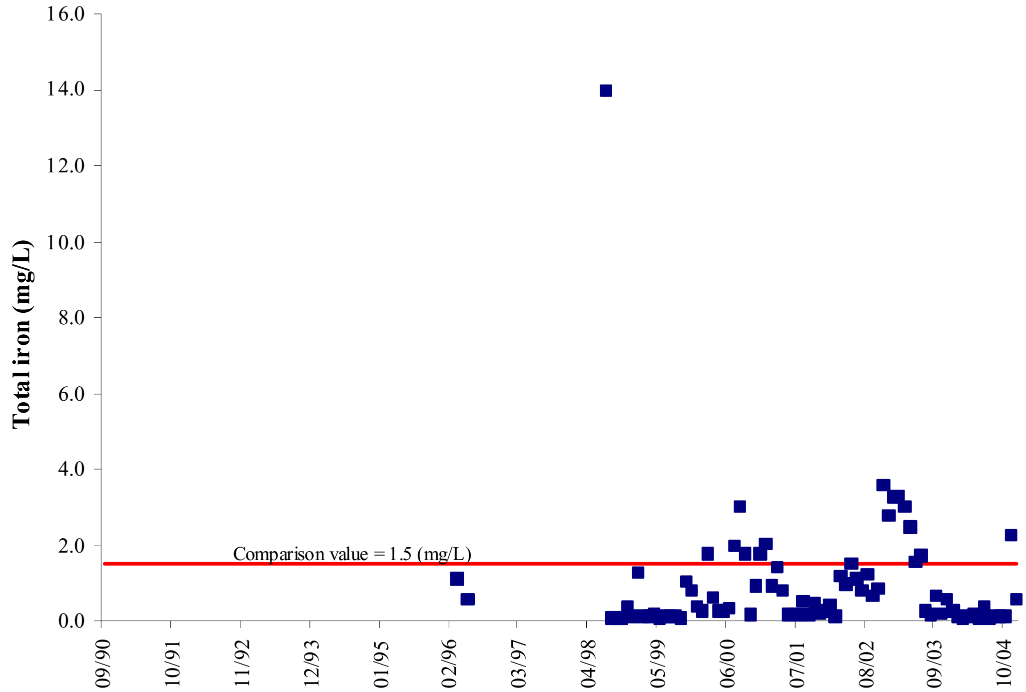

Figure 7.37 Total iron concentrations at DMME MPID 6084658.

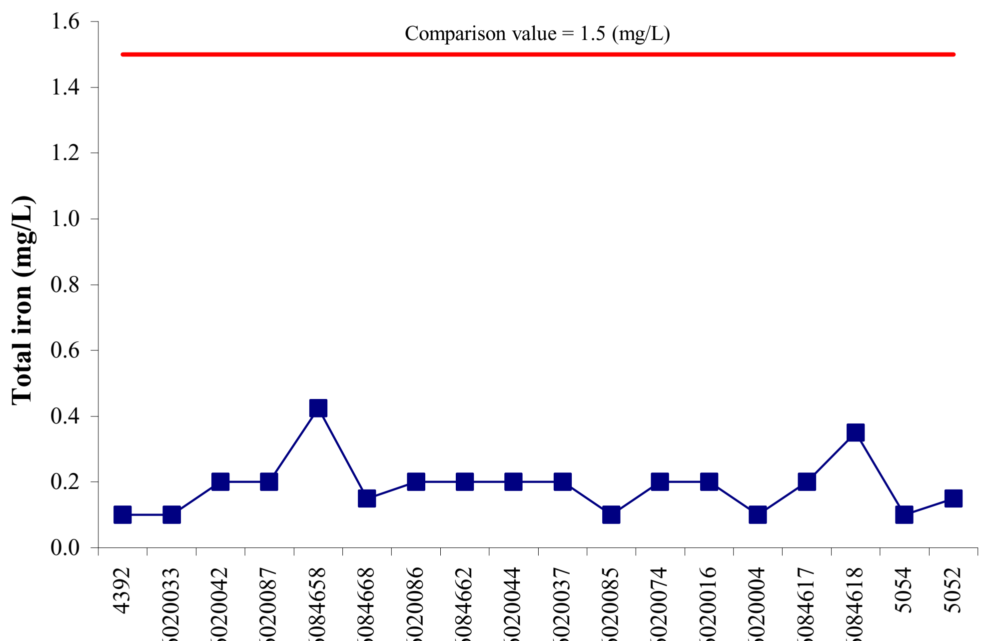

Figure 7.38 Median total iron concentrations at DMME MPID sites in Knox Creek.

7.3.5 Sulfate

Sulfate concentrations exceeded the 90th percentile screening value (76 mg/L) in more than 10% of the samples collected at VADEQ monitoring station 6AKOX006.52 (Figure 7.39). In addition, sulfate concentrations exceeded the 90th percentile screening value in more than 10% of the samples collected at 12 of 13 DMME MPID sites (Figures 7.40 through 7.51). Median sulfate concentrations for the monitoring stations on Knox Creek are shown in Figure 7.52. The EPA used sulfate concentrations as an indicator of impaired macroinvertebrate communities in mid-Atlantic highland streams (Klemm et al., 2001). Other studies note that sulfate is a reliable indicator of mining activity and is often linked to depressed benthic health but, by itself, has not been shown to actually cause a reduction in the health of benthic communities (Merricks, 2003). Sulfate is, however, a principle component of total dissolved solids, which have been shown to impair benthic macroinvertebrate communities. There is a public water supply water quality standard of 250 mg/L but this is for taste and odor control and does not apply to aquatic life. Therefore sulfate is considered a possible stressor.

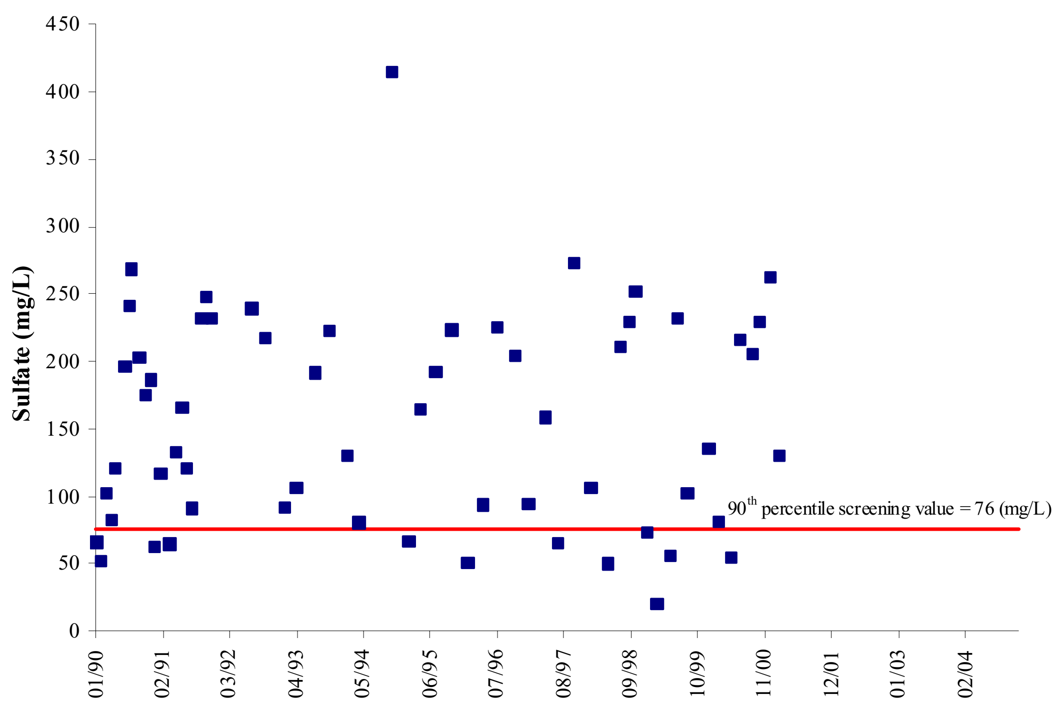

Figure 7.39 Sulfate concentrations at VADEQ monitoring station 6AKOX006.52.

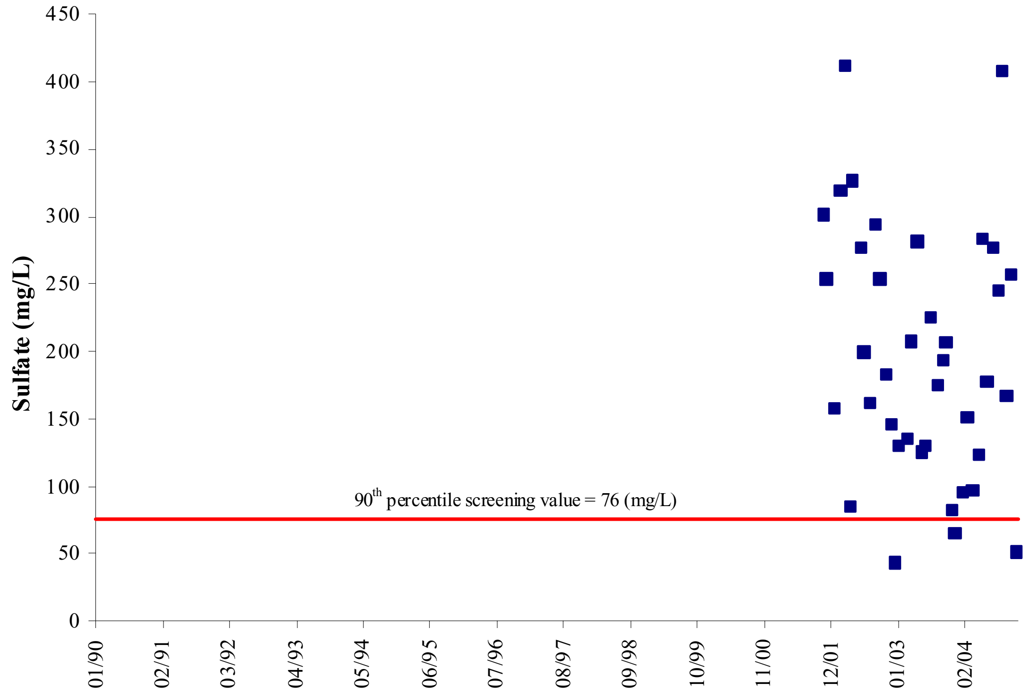

Figure 7.40 Sulfate concentrations at DMME MPID 4392 on Knox Creek.

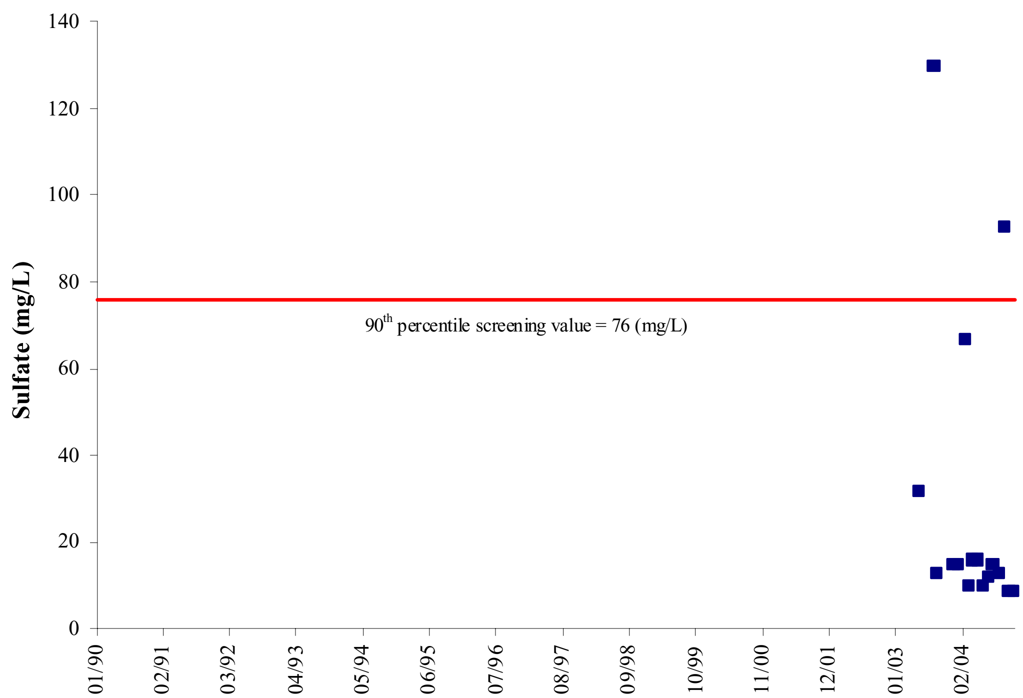

Figure 7.41 Sulfate concentrations at DMME MPID 5052 on Knox Creek.

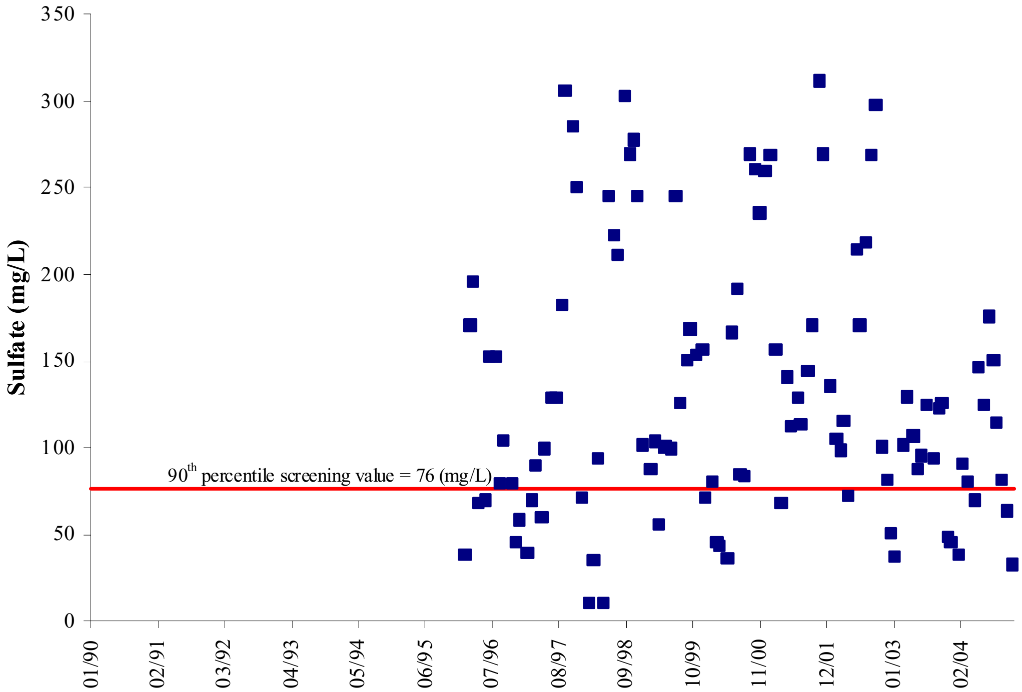

Figure 7.42 Sulfate concentrations at DMME MPID 6020004 on Knox Creek.

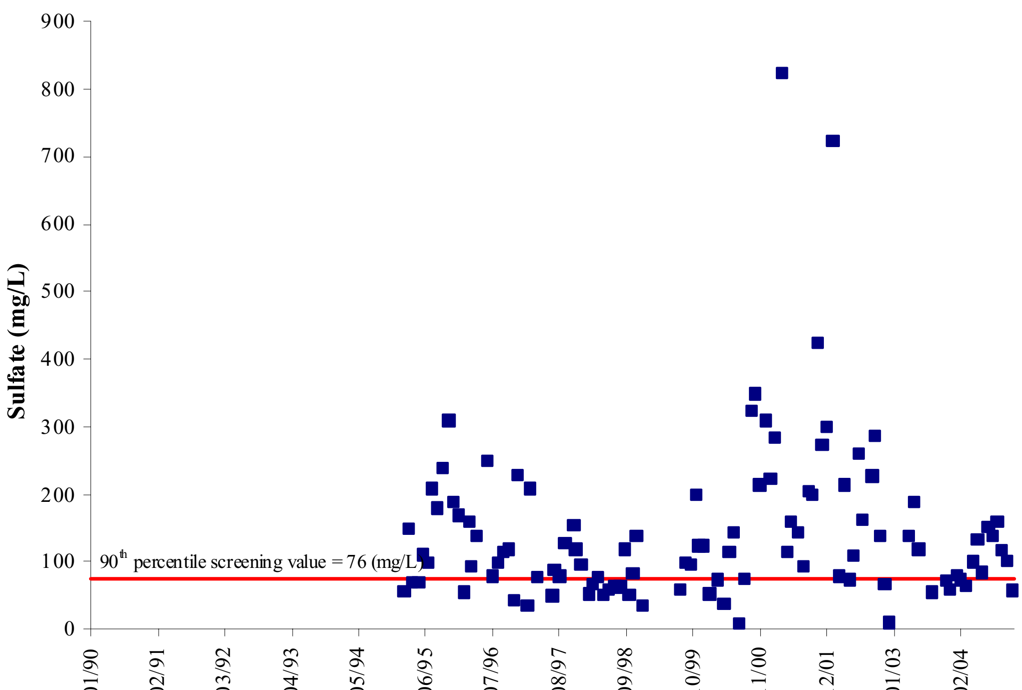

Figure 7.43 Sulfate concentrations at DMME MPID 6020016 on Knox Creek.

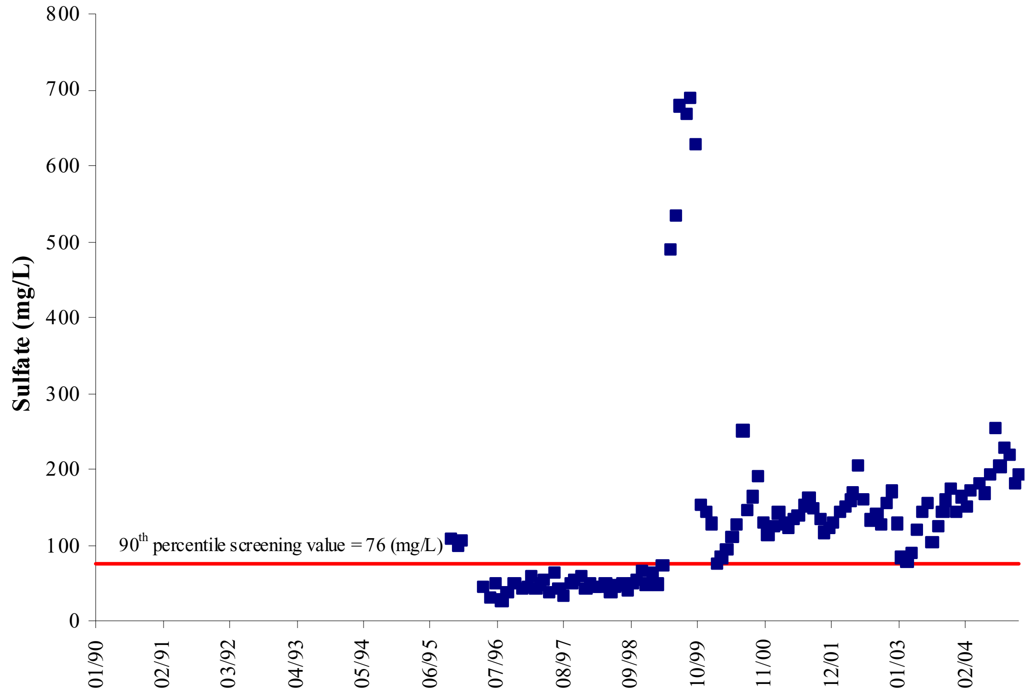

Figure 7.44 Sulfate concentrations at DMME MPID 6020033 on Knox Creek.

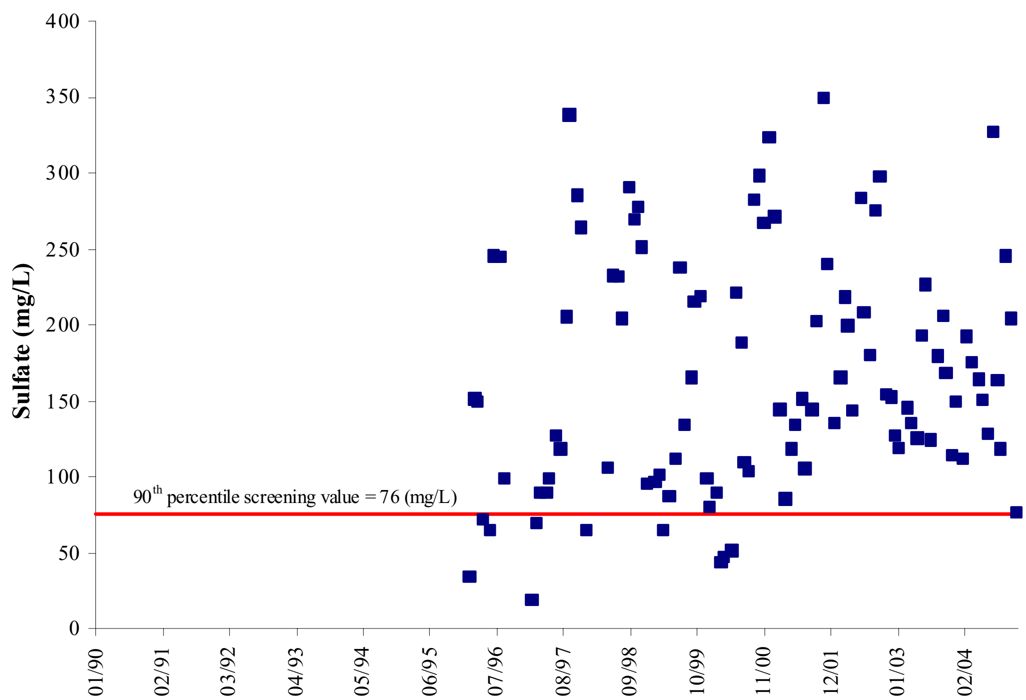

Figure 7.45 Sulfate concentrations at DMME MPID 6020037 on Knox Creek.

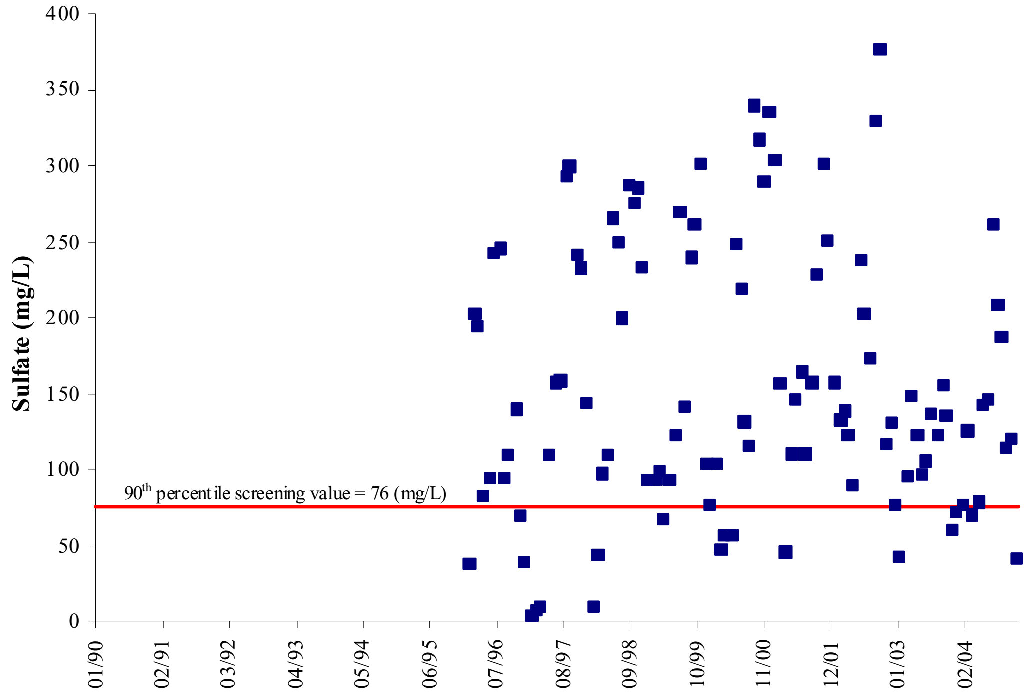

Figure 7.46 Sulfate concentrations at DMME MPID 6020042 on Knox Creek.

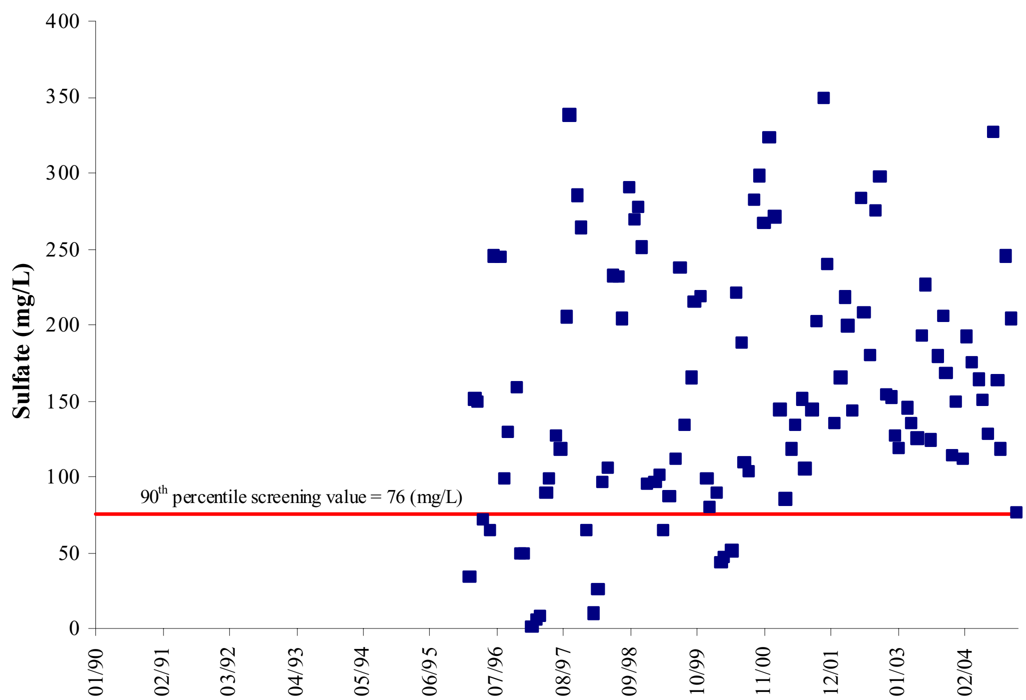

Figure 7.47 Sulfate concentrations at DMME MPID 6020044 on Knox Creek.

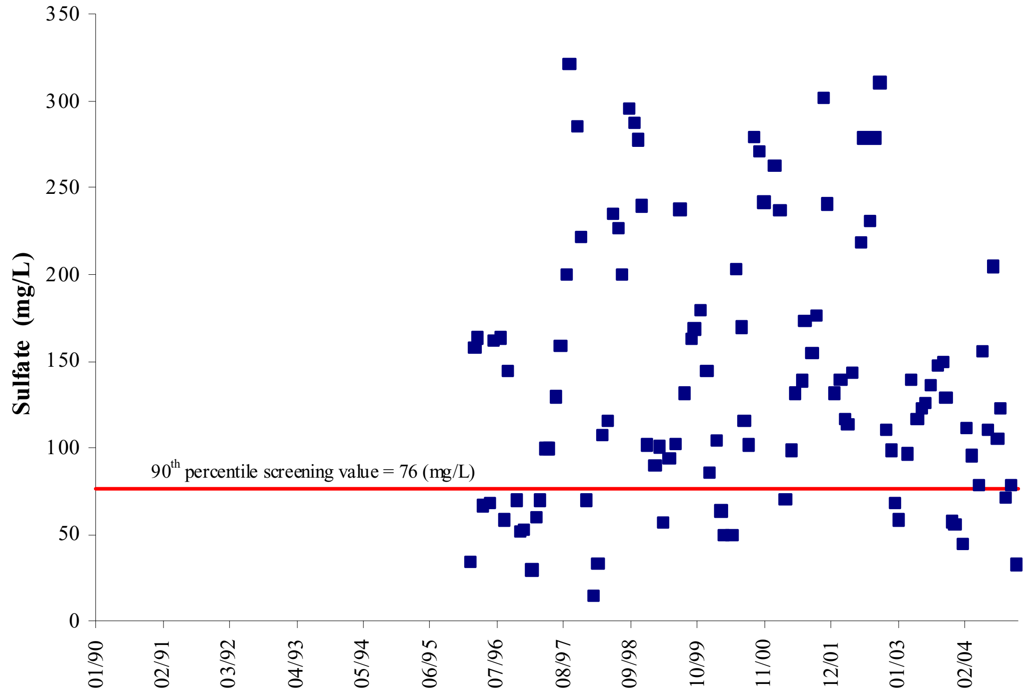

Figure 7.48 Sulfate concentrations at DMME MPID 6020074 on Knox Creek.

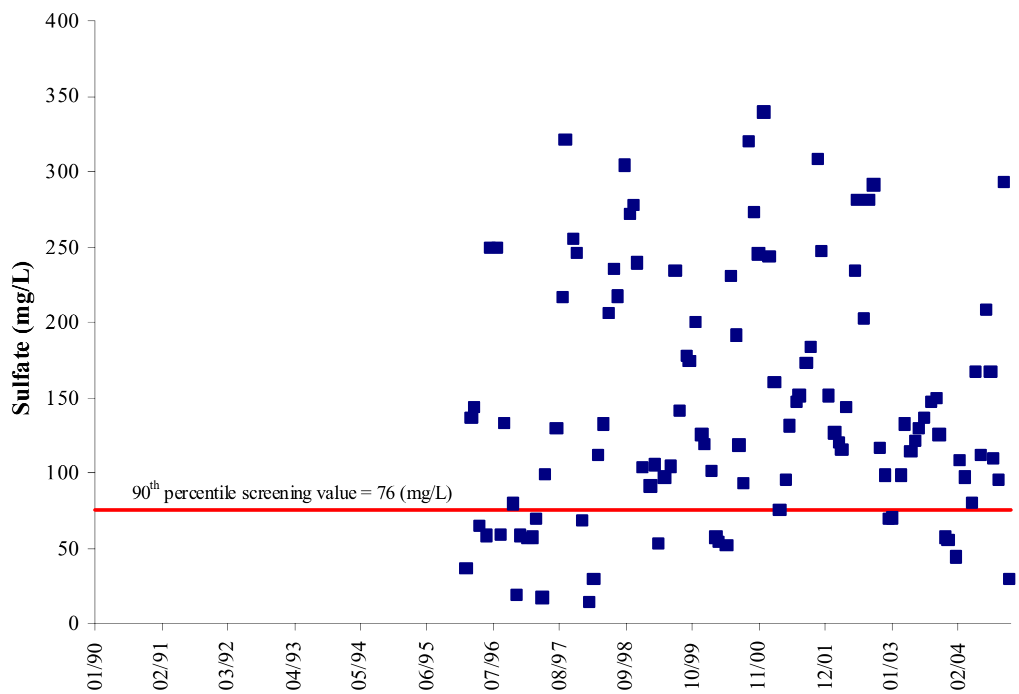

Figure 7.49 Sulfate concentrations at DMME MPID 6020085 on Knox Creek.

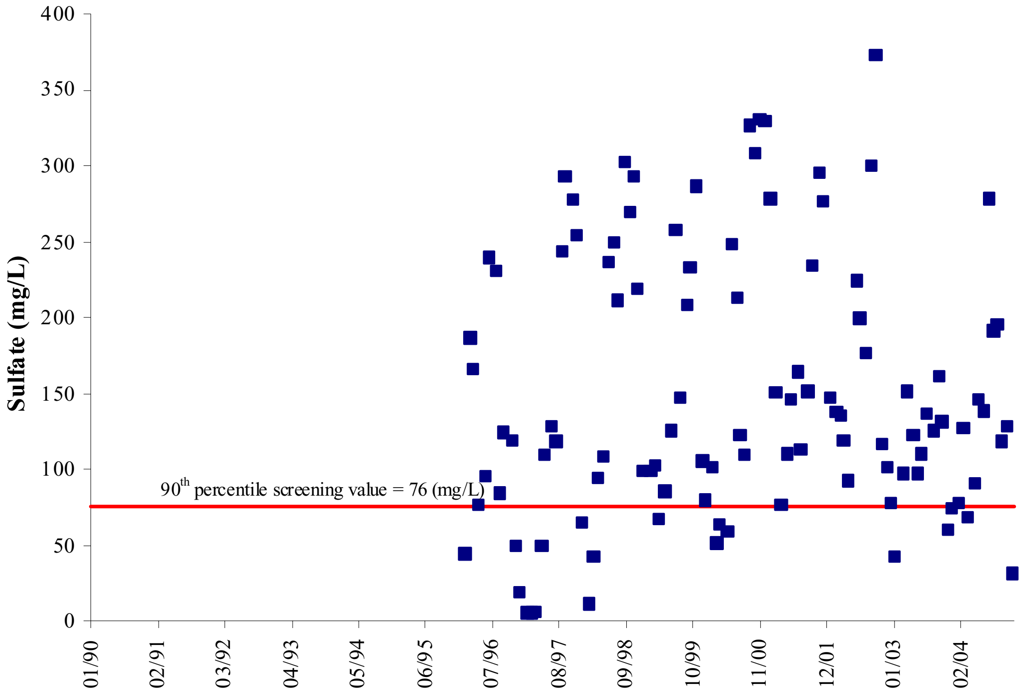

Figure 7.50 Sulfate concentrations at DMME MPID 6020086 on Knox Creek.

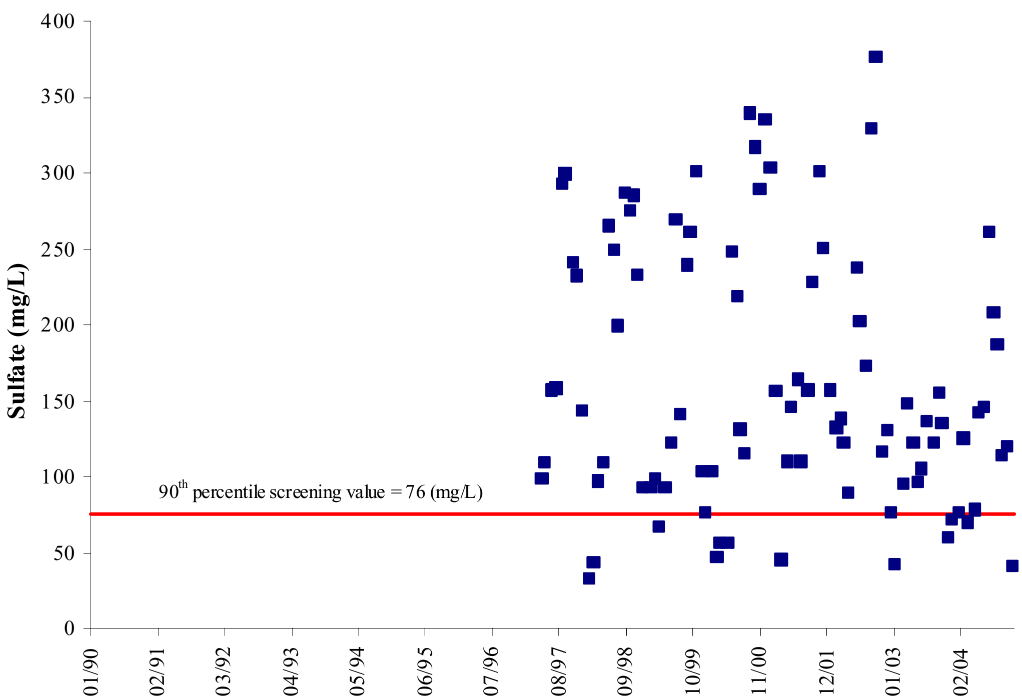

Figure 7.51 Sulfate concentrations at DMME MPID 6020087 on Knox Creek.

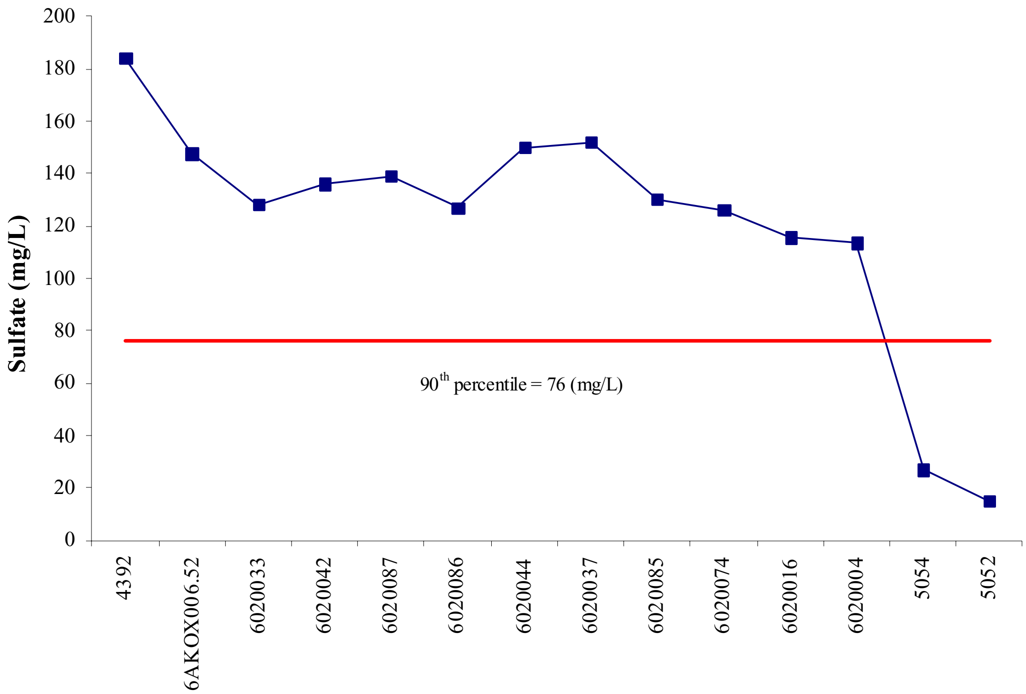

Figure 7.52 Median sulfate concentrations in Knox Creek.

7.3.6 Sediment

Total suspended solids (TSS) concentrations exceeded the 90th percentile screening value (30 mg/L) at VADEQ monitoring station 6AKOX006.52 in more than 10% of the samples collected (Figure 7.53). VADEQ monitoring station 6AKOX014.17 only had six data points but one was the highest concentration recorded in the dataset (1,386 mg/L on 5/2/2002). At two DMME MPIDs (6020016 and 6084618) more than 10% of the samples collected exceed the 90th percentile screening value (Figures 7.54 and 7.55). At four additional DMME sites (6020004, 6020033, 6020042, 6020087) Knox Creek had a very high concentration that exceeded 100 mg/L (Figures 7.56 through 7.59). Median TSS concentrations for the monitoring stations in Knox Creek are shown in Figure 7.60.

The only habitat data available from VADEQ was collected in May 2005. Embeddedness and pool sediment deposition both had very good scores (section 6.4). Additional habitat data was available from the State of Kentucky collected in July 2002 at the Virginia/Kentucky state line. Embeddedness scored very high in this survey, but pool sediment was in the marginal category. Based on the most recent habitat scores and the fact that total suspended solids concentrations were not persistently high at most of the DMME MPIDs sediment is considered a possible stressor in Knox Creek.

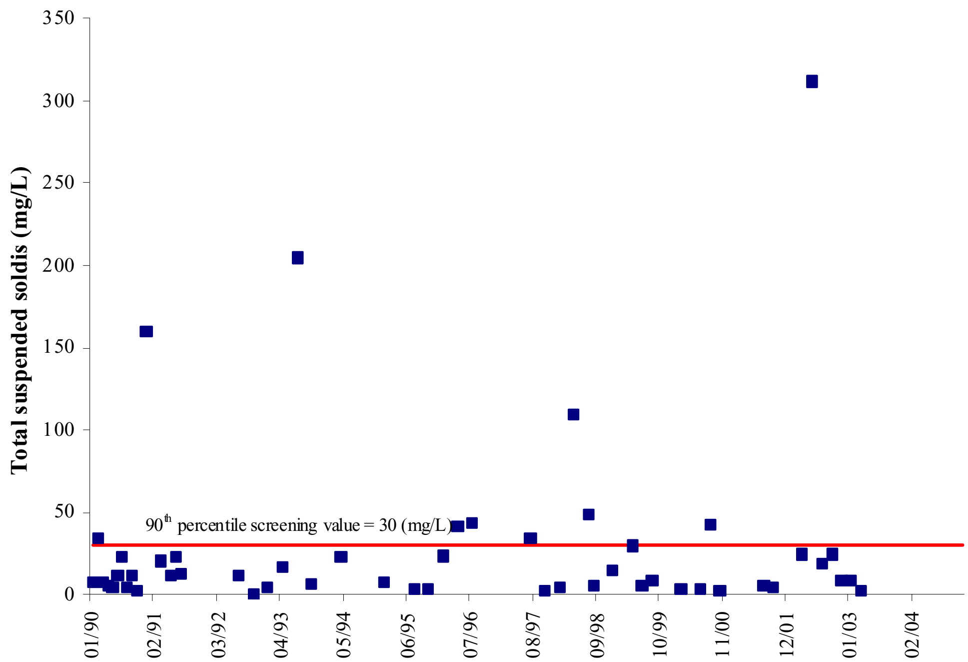

Figure 7.53 TSS concentrations at VADEQ station 6AKOX006.52 on Knox Creek.

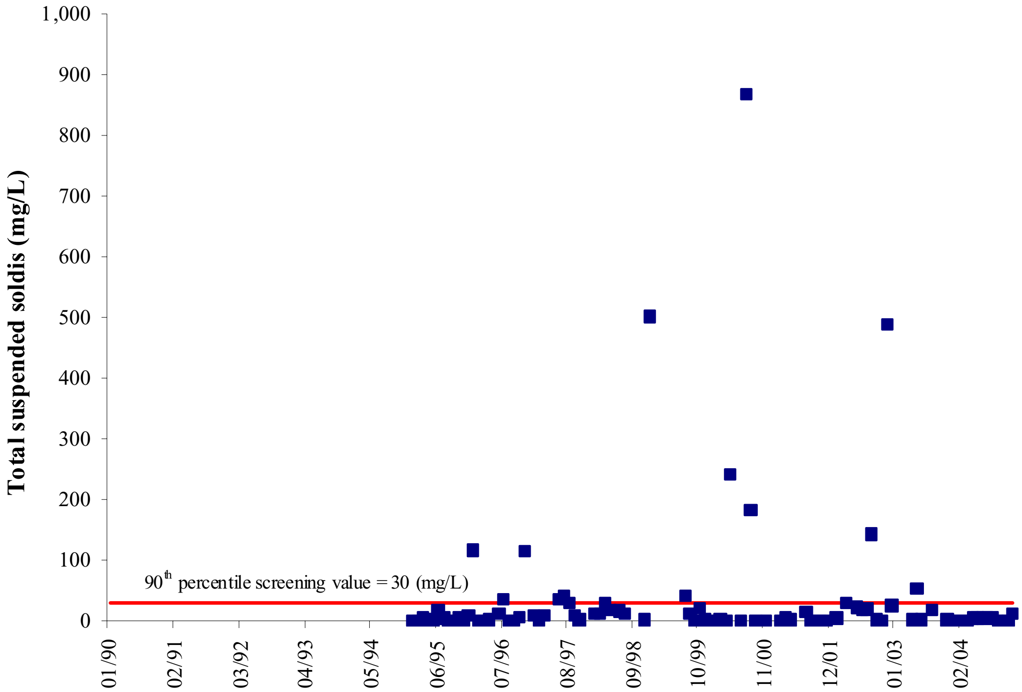

Figure 7.54 TSS concentrations at DMME MPID 6020016 on Knox Creek.

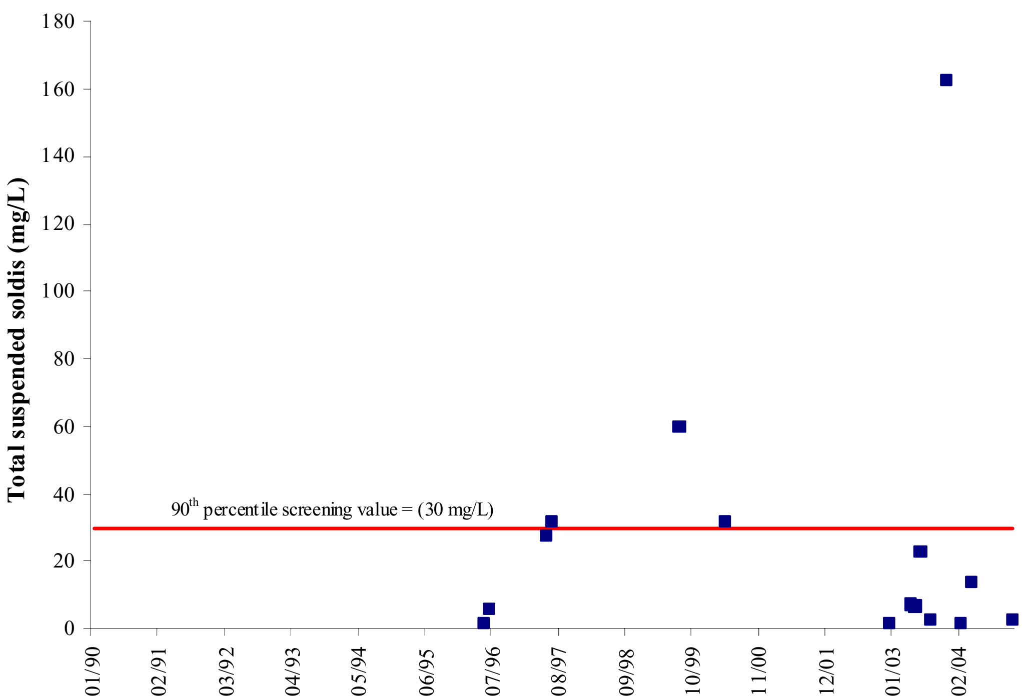

Figure 7.55 TSS concentrations at DMME MPID 6084618 on Knox Creek.

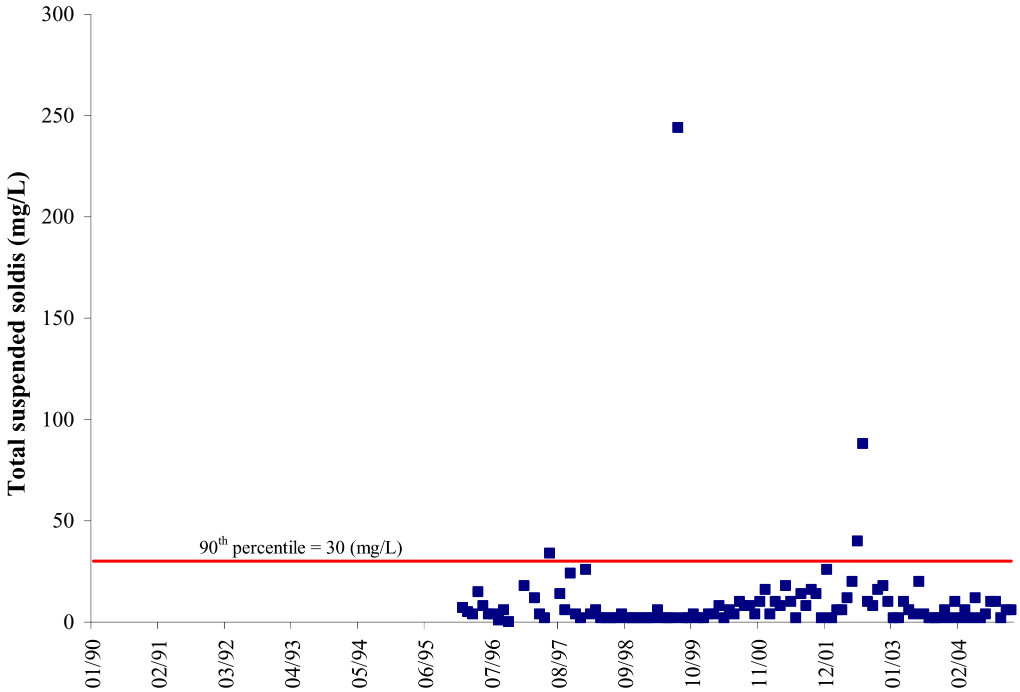

Figure 7.56 TSS concentrations at DMME MPID 6020004 on Knox Creek.

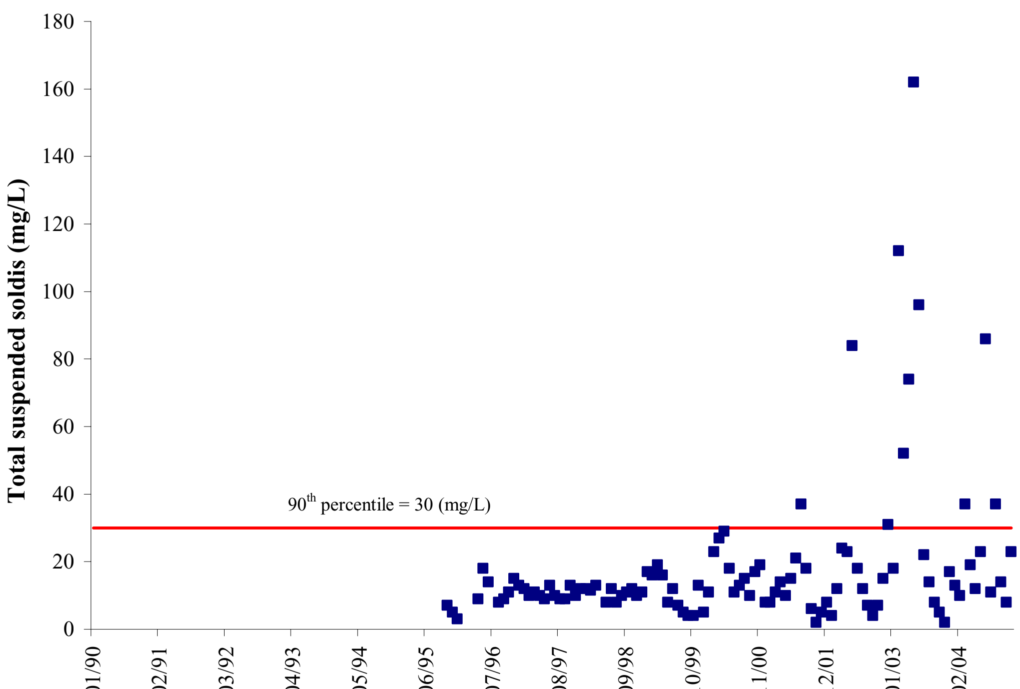

Figure 7.57 TSS concentrations at DMME MPID 6020033 on Knox Creek.

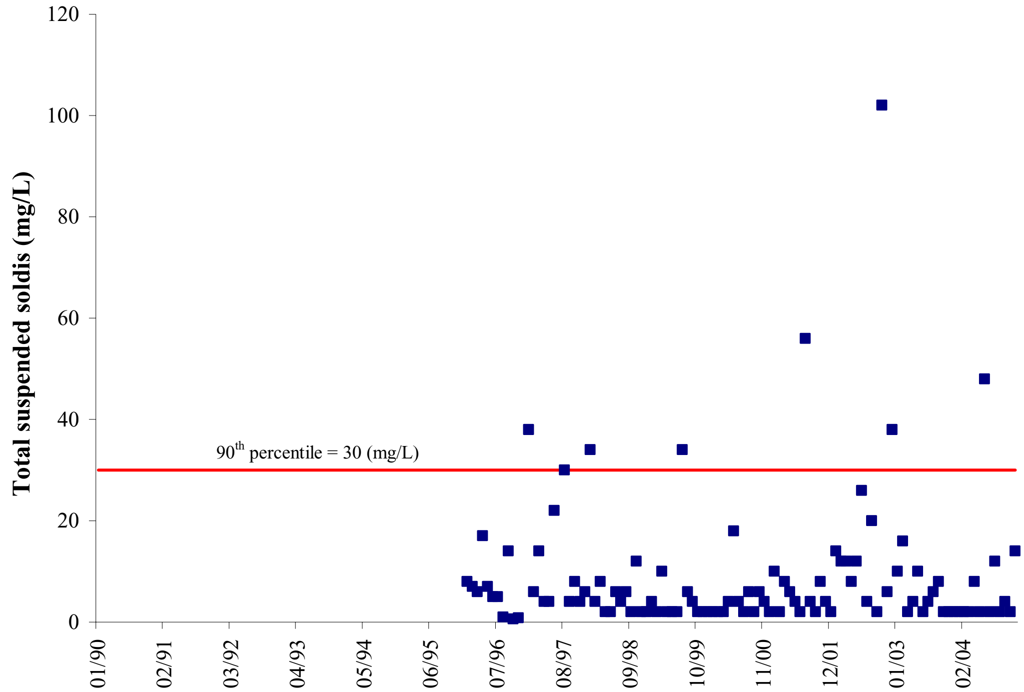

Figure 7.58 TSS concentrations at DMME MPID 6020042 on Knox Creek.

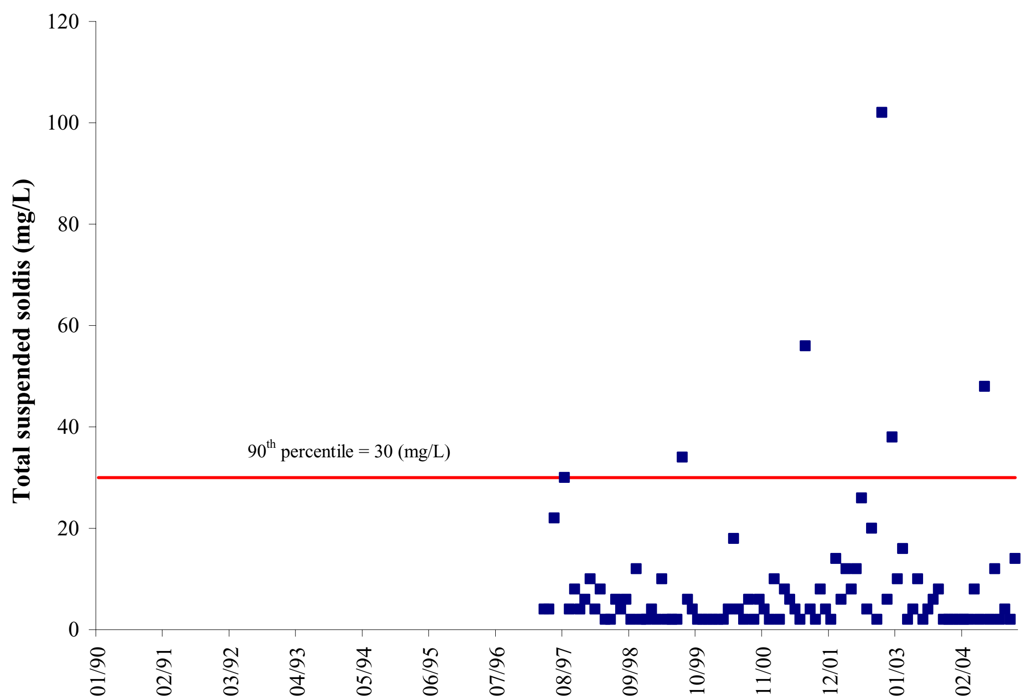

Figure 7.59 TSS concentrations at DMME MPID 6020087 on Knox Creek.

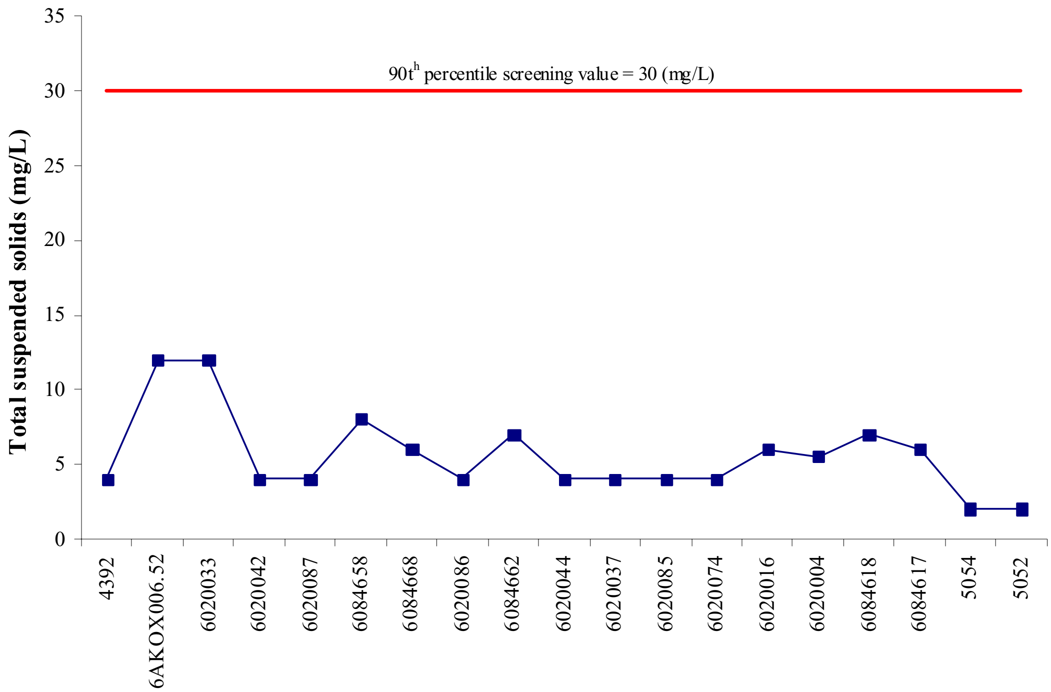

Figure 7.60 Median TSS concentrations at DMME MPIDs on Knox Creek.

7.4 Probable Stressor

Table 7.3 Probable stressors in Knox Creek.

Parameter	Location in Document
Conductivity/Total dissolved solids	section 7.4.1

7.4.1 Conductivity/Total dissolved solids (TDS)

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. TDS is a measure of the actual concentration of the dissolved ions, dissolved metals, minerals, and organic matter in water. Dissolved ions can include sulfate, calcium carbonate, chloride, etc. Therefore, even though they are two different measurements, there is a direct correlation between conductivity and TDS. In the Knox Creek data set there was a Pearson Product Moment Correlation of 0.922 between conductivity and TDS.

High conductivity values have been linked to poor benthic health (Merricks, 2003) and elevated conductivity is common with land disturbance and mine drainages. A recent report on the effects of surface mining on headwater stream biotic integrity in Eastern Kentucky noted that one of the most significant stressors in these watersheds was elevated TDS (Pond, 2004). Elevated TDS concentrations impact pollution sensitive mayflies the most. Figure 7.61 from this report shows that "drastic reductions in mayflies occurred at sites with conductivities generally above 500 μmhos/cm" (Pond, 2004).

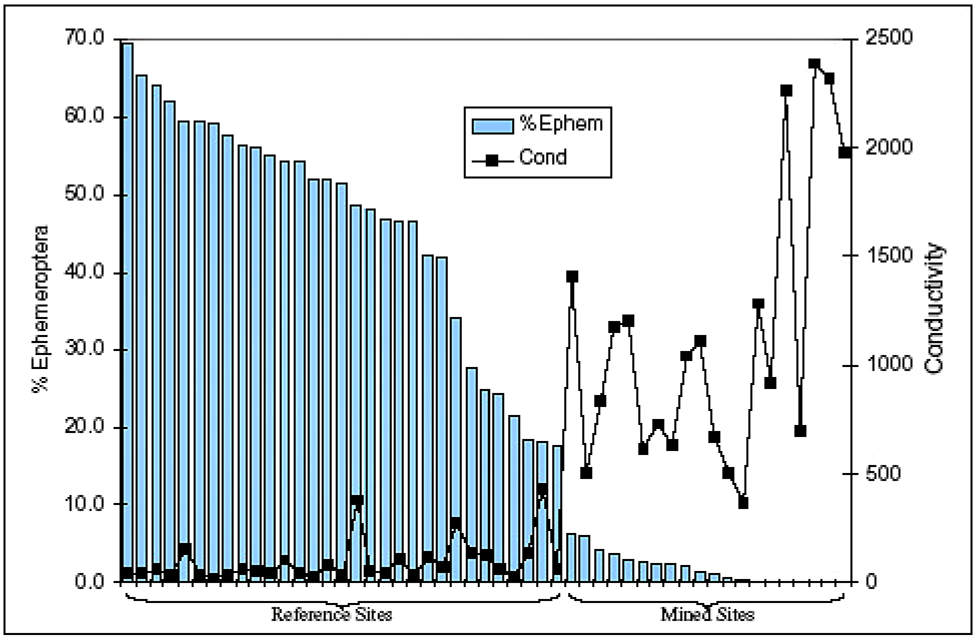

Figure 7.61 The relationship between %Ephemeroptera and conductivity from reference and mined sites (Pond, 2004).

Pond speculated that the increased salinity may irritate the gill structures on mayflies and inhibit the absorption of oxygen, but research has not confirmed this. A typical reference station in this part of the state can be expected to have at least nearly 50% mayflies out of the total assemblage. The results of a VADEQ benthic survey in Fall 1993 showed mayflies only made up 3% of the total benthic assemblage. The percentage of mayflies improved in the Spring 2005 survey to 39%; however, they were all members of the more pollution tolerant families (Caenidae, Baetidae, and Isonychiidae). In the development of both the Virginia and West Virginia Stream Condition Indices, the reference streams used had conductivity levels that did not exceed 500 µmhos/cm. In the absence of a Virginia water quality standard, the 90th percentile screening value of 402 µmhos/cm was used. Conductivity values at both VADEQ stations consistently exceeded the 90th percentile screening value (Figures 7.62 and 7.63). In data provided by DMME, the 90th percentile screening value was consistently exceeded at 14 of the 17 sites with nine or more conductivity values (Figures 7.64 through 7.77). Median conductivity values for all of the VADEQ and DMME MPIDs are shown in Figure 7.78.

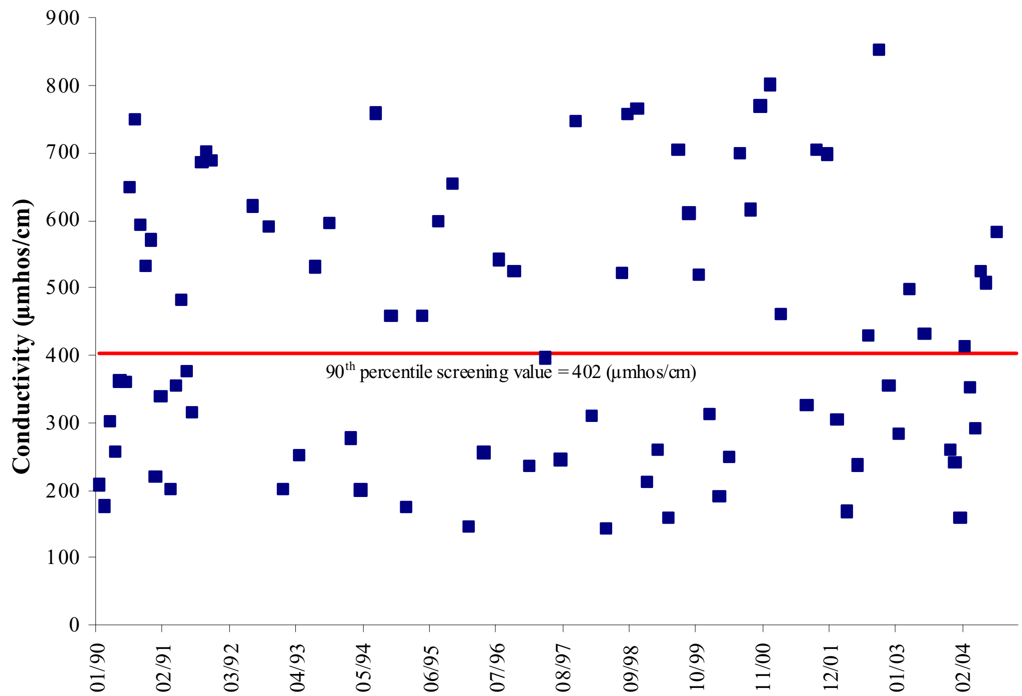

Figure 7.62 Conductivity measurements at VADEQ station 6AKOX006.52.

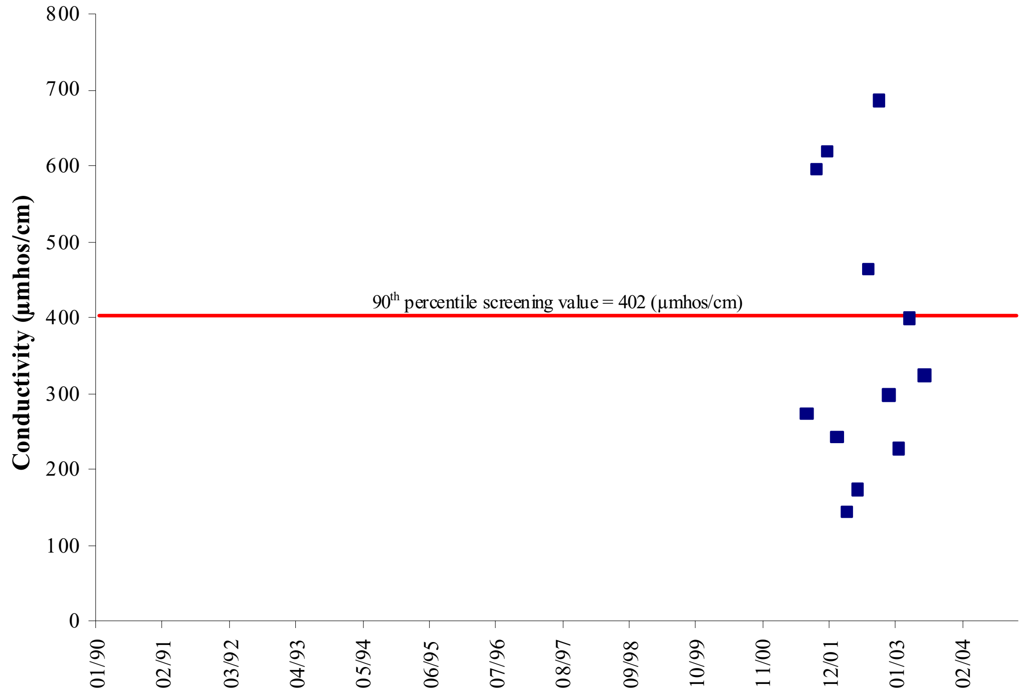

Figure 7.63 Conductivity measurements at VADEQ station 6AKOX014.17.

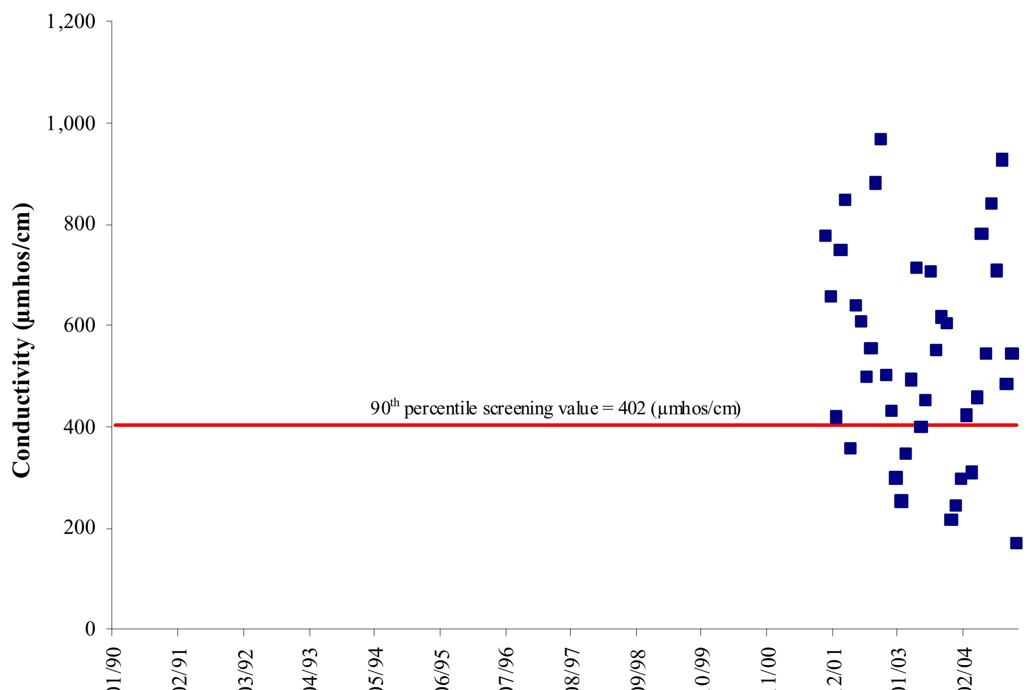

Figure 7.64 Conductivity measurements at DMME MPID 4392.

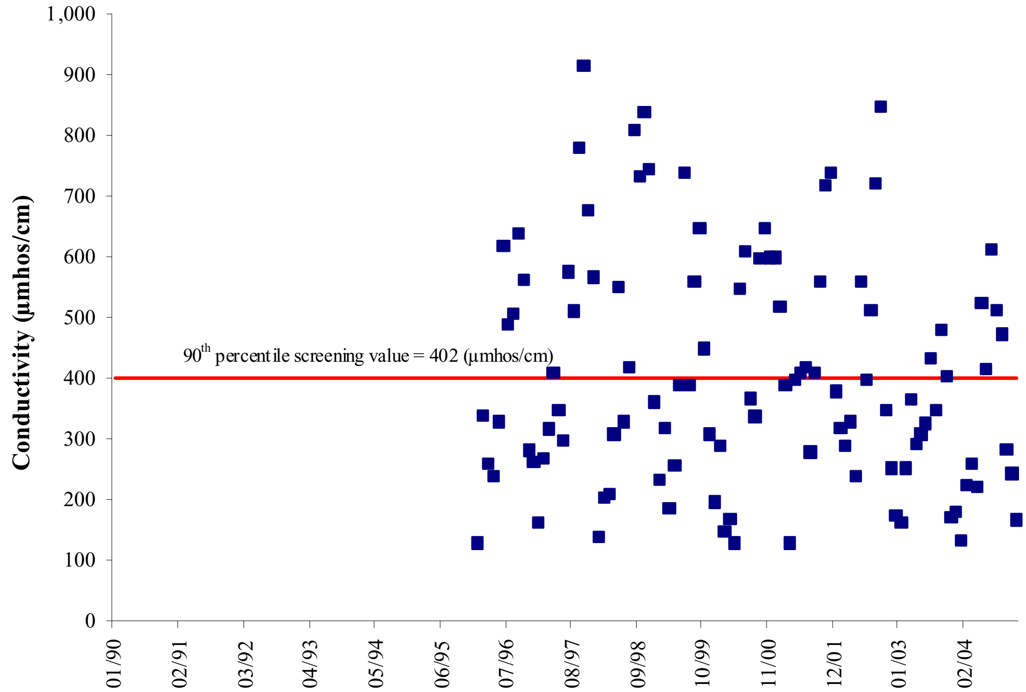

Figure 7.65 Conductivity measurements at DMME MPID 6020004.

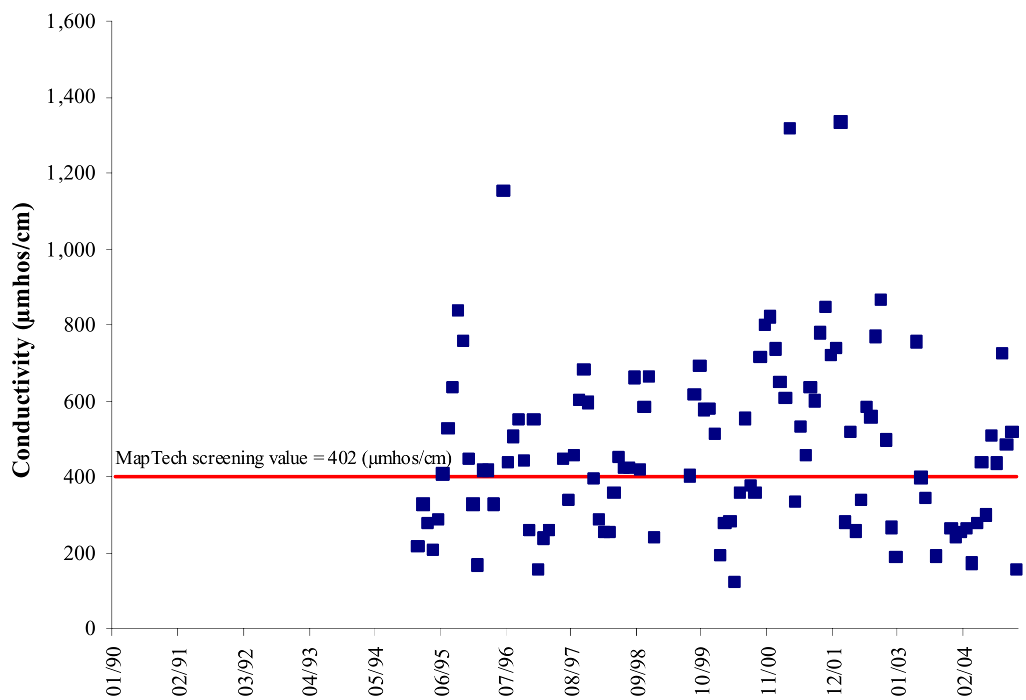

Figure 7.66 Conductivity measurements at DMME MPID 6020016.

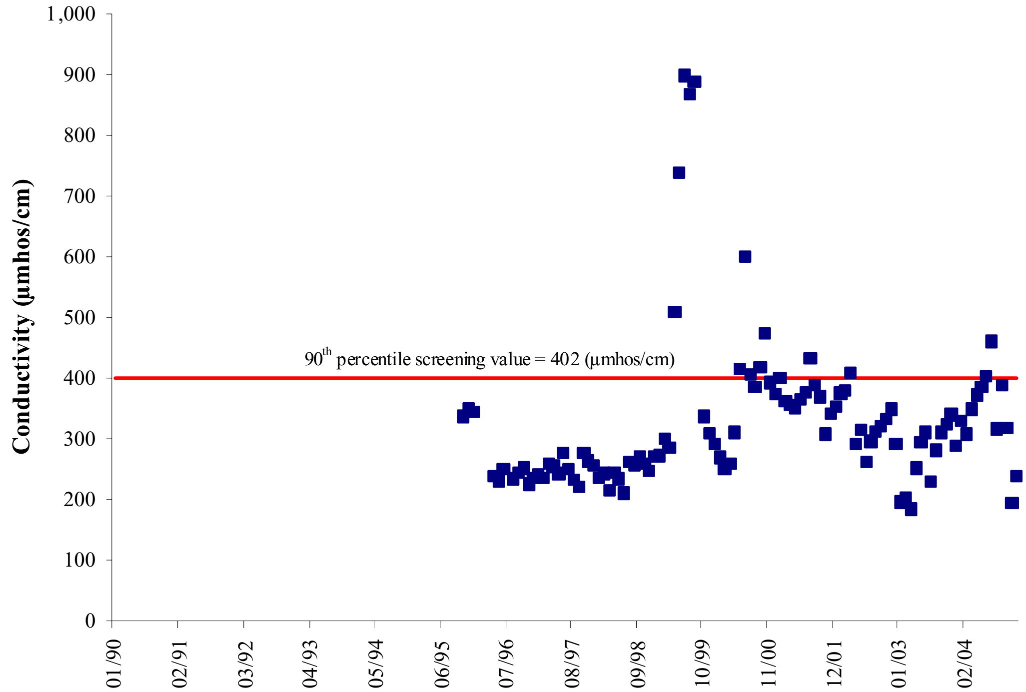

Figure 7.67 Conductivity measurements at DMME MPID 6020033.

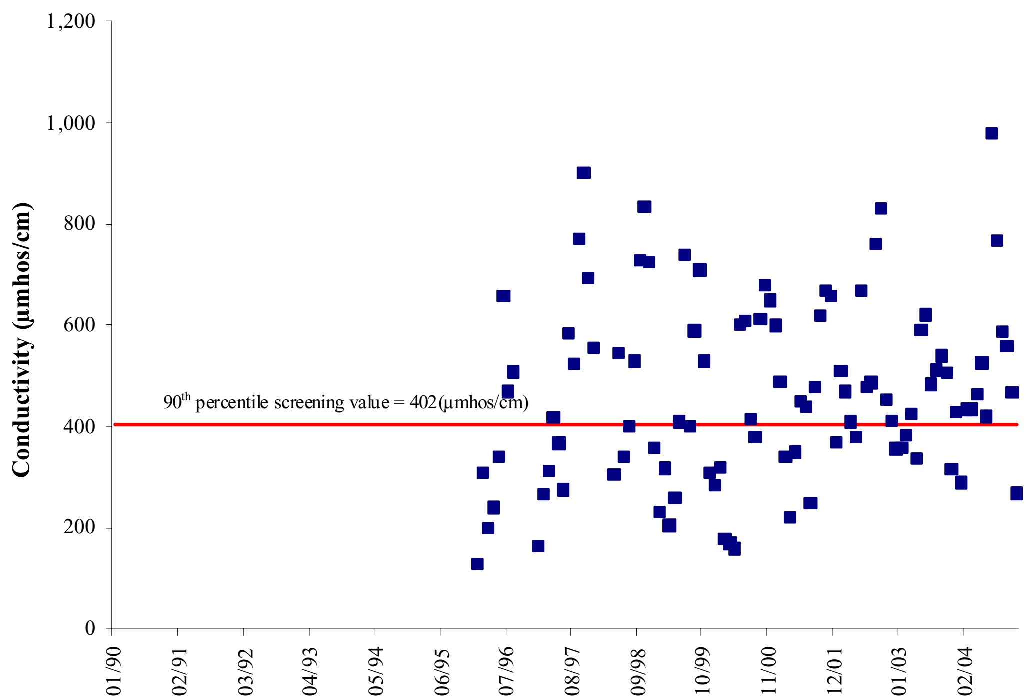

Figure 7.68 Conductivity measurements at DMME MPID 6020037.

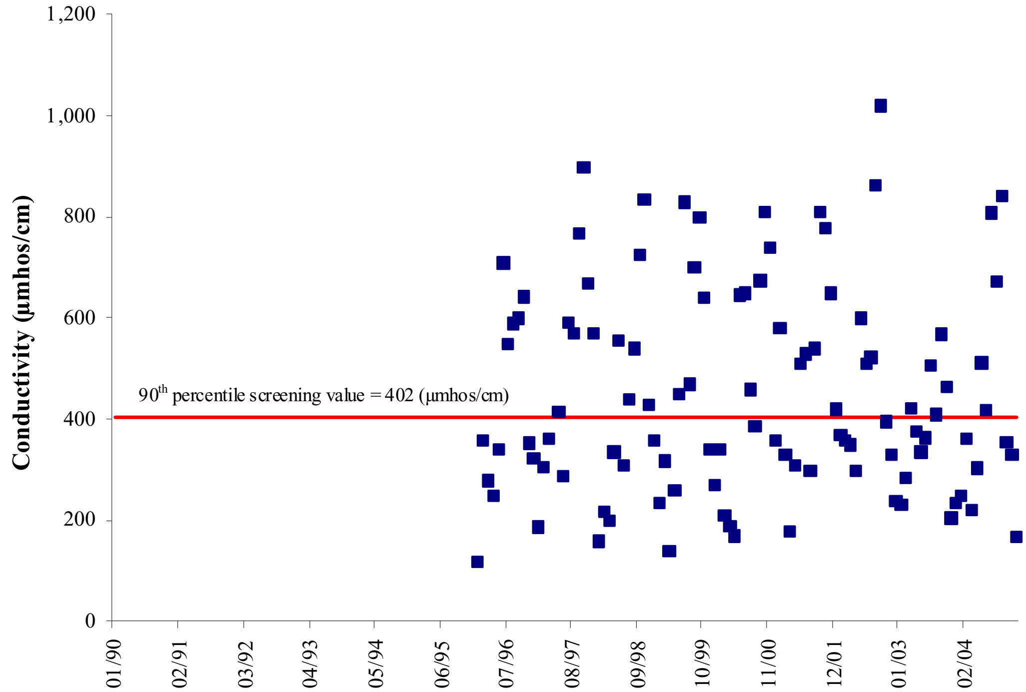

Figure 7.69 Conductivity measurements at DMME MPID 6020042.

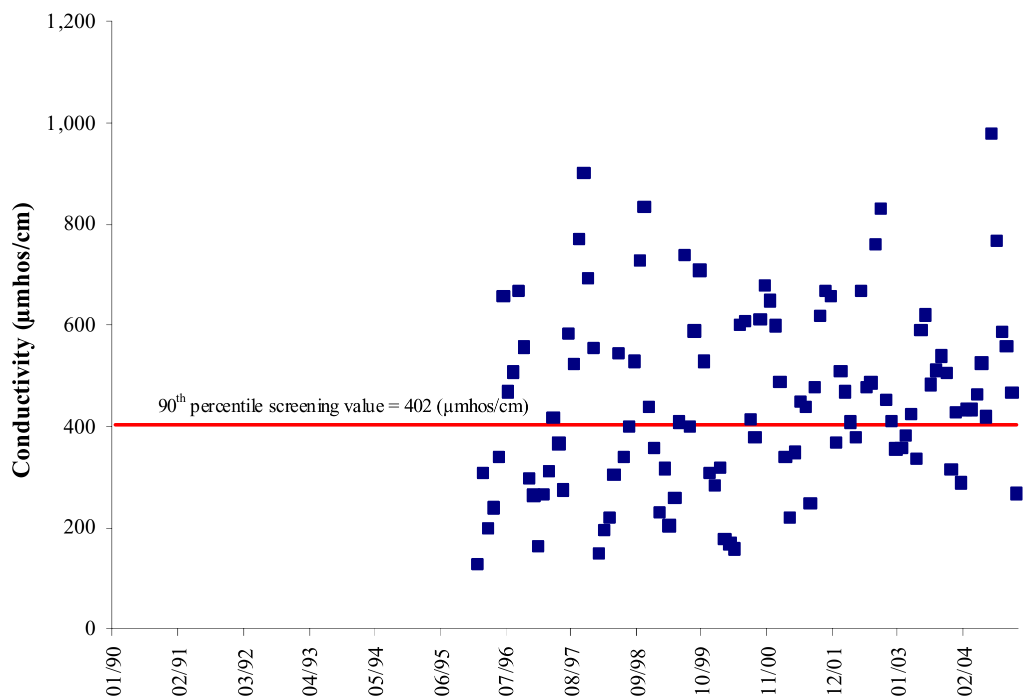

Figure 7.70 Conductivity measurements at DMME MPID 6020044.

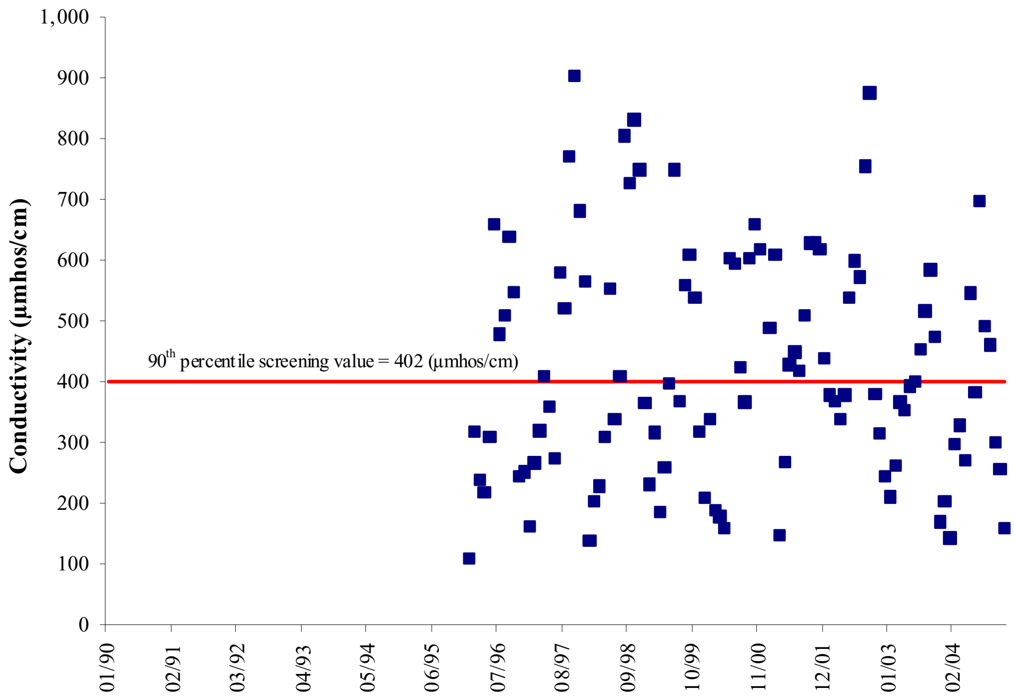

Figure 7.71 Conductivity measurements at DMME MPID 6020074.

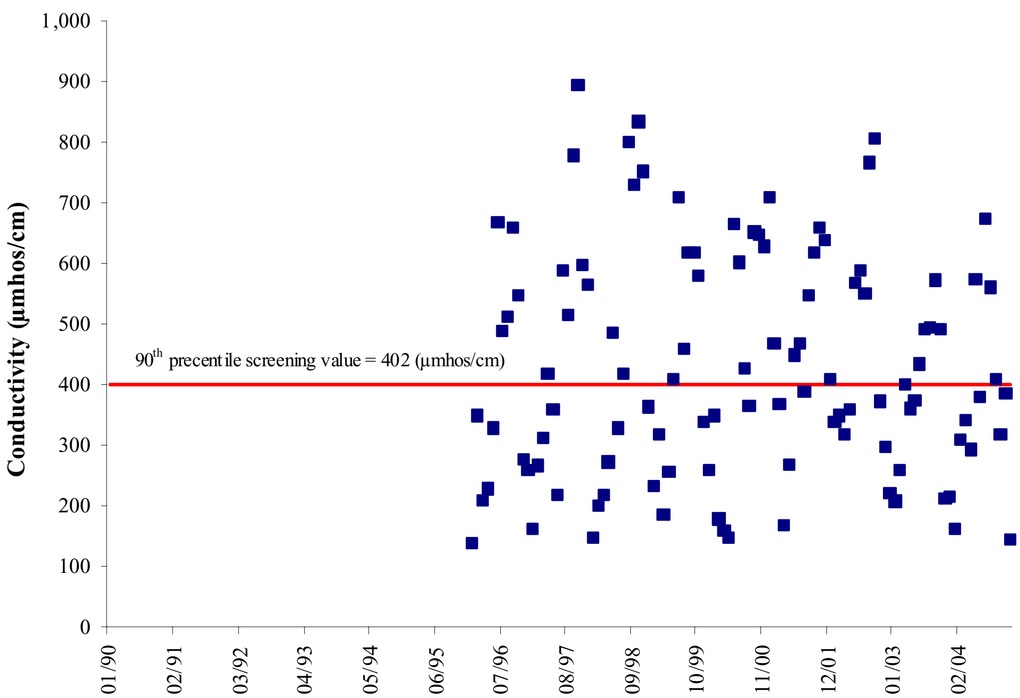

Figure 7.72 Conductivity measurements at DMME MPID 6020085.

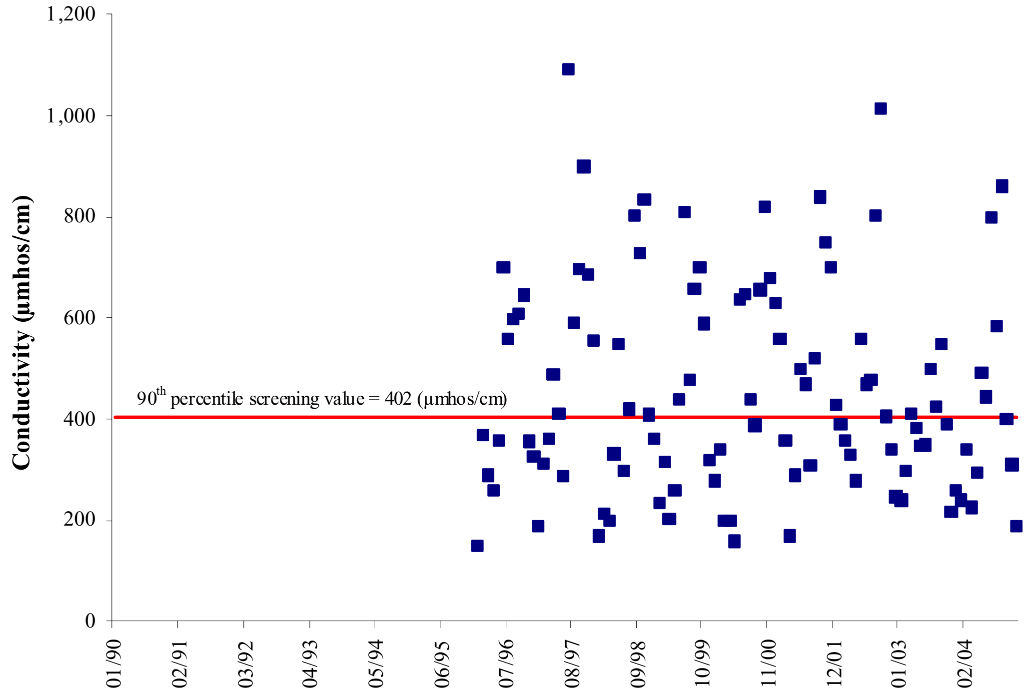

Figure 7.73 Conductivity measurements at DMME MPID 6020086.

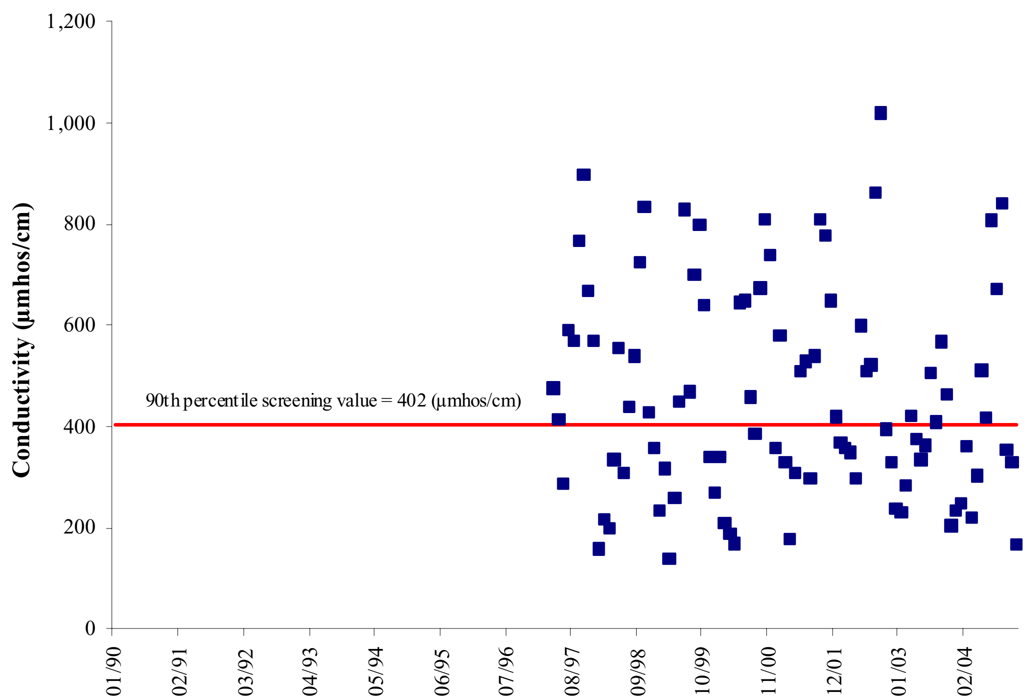

Figure 7.74 Conductivity measurements at DMME MPID 6020087.

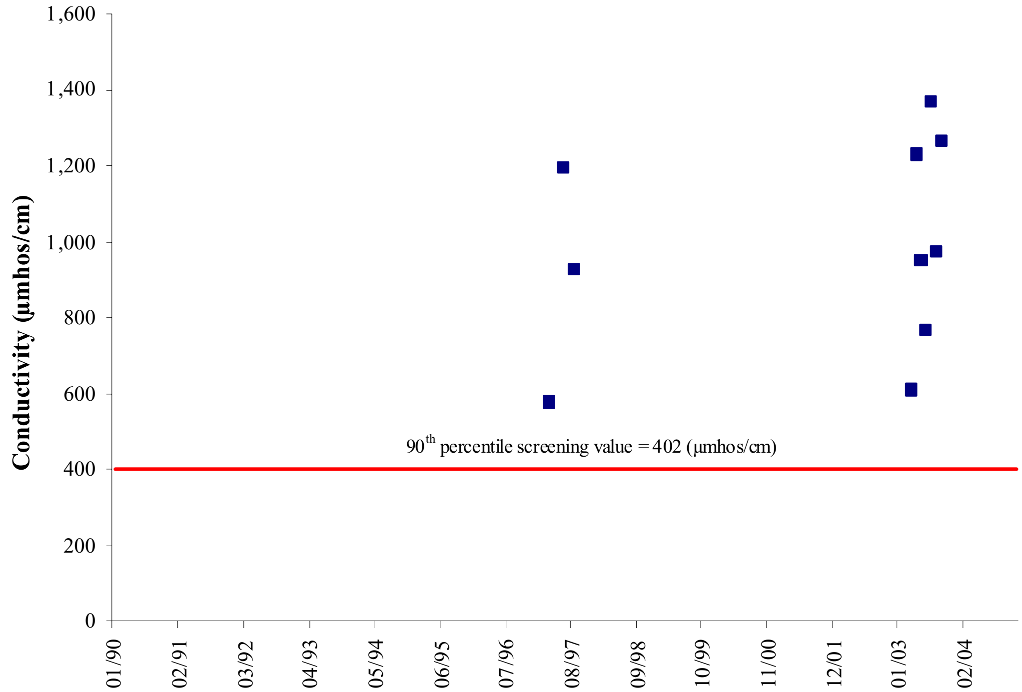

Figure 7.75 Conductivity measurements at DMME MPID 6084617.

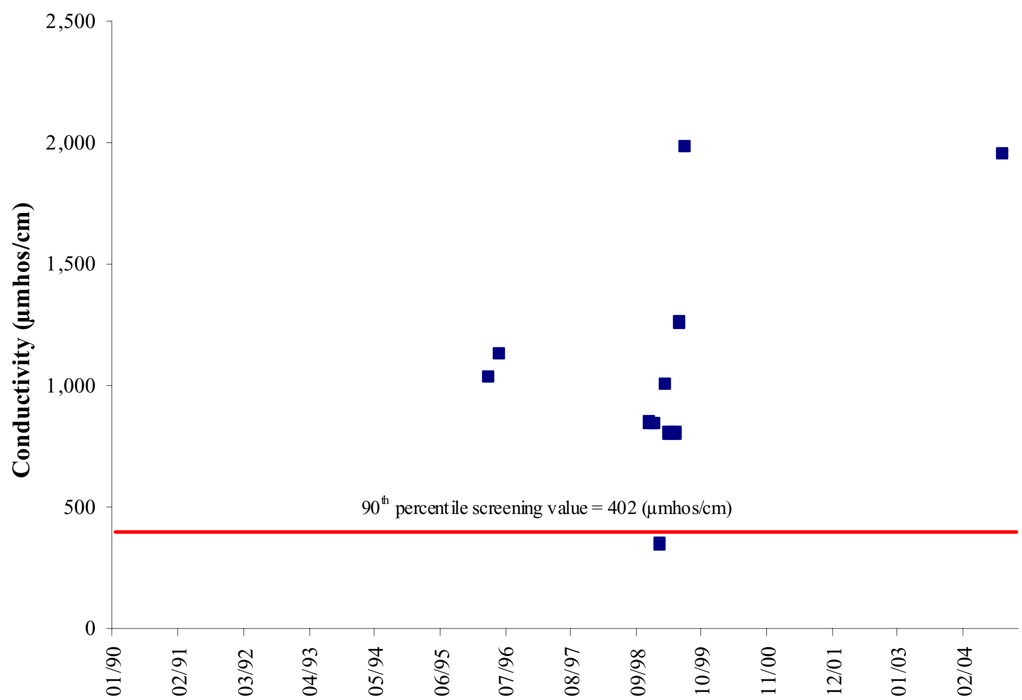

Figure 7.76 Conductivity measurements at DMME MPID 6084658.

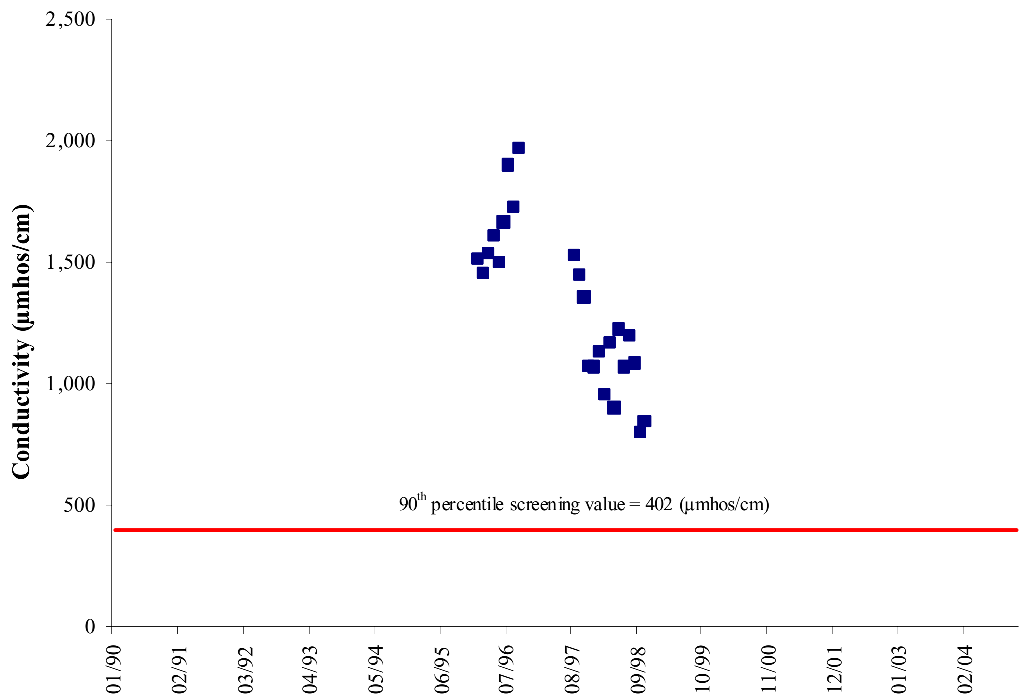

Figure 7.77 Conductivity measurements at DMME MPID 6084668.

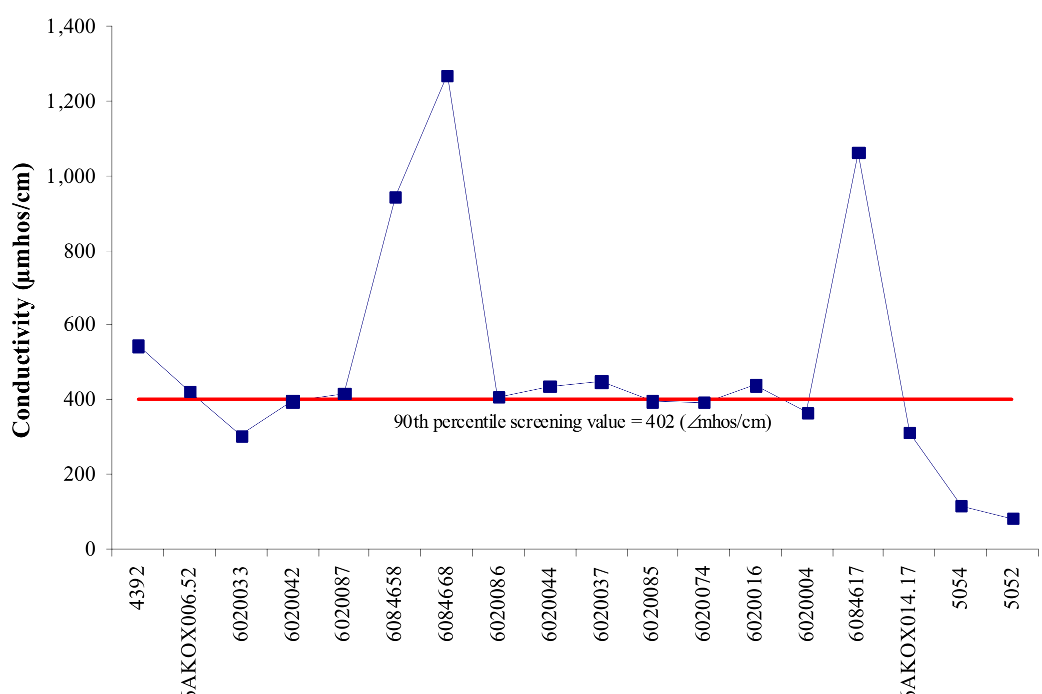

Figure 7.78 Median conductivity values in Knox Creek.

The TDS 90th percentile screening value was 260 mg/L. TDS concentrations consistently exceeded this value at VADEQ monitoring station 6AKOX006.52. TDS concentrations consistently exceeded 260 mg/L at 10 of the 13 DMME MPIDs that had nine or more data points (Figures 7.79 through 7.89). Median TDS values for the DMME MPIDs are shown in Figure 7.90.

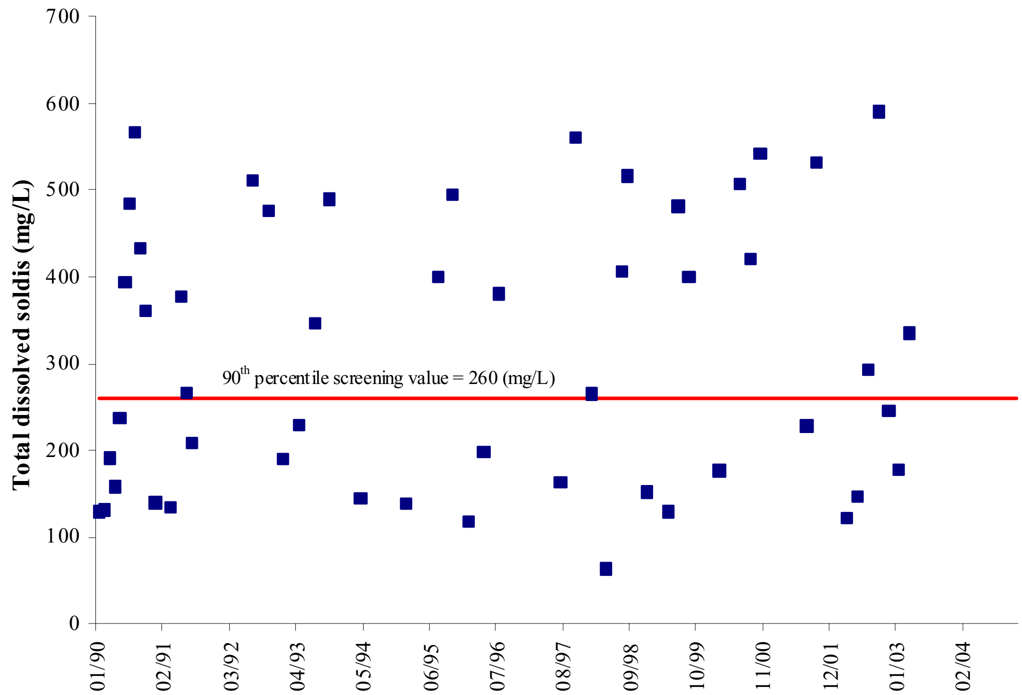

Figure 7.79 TDS concentrations at VADEQ station 6AKOX006.52.

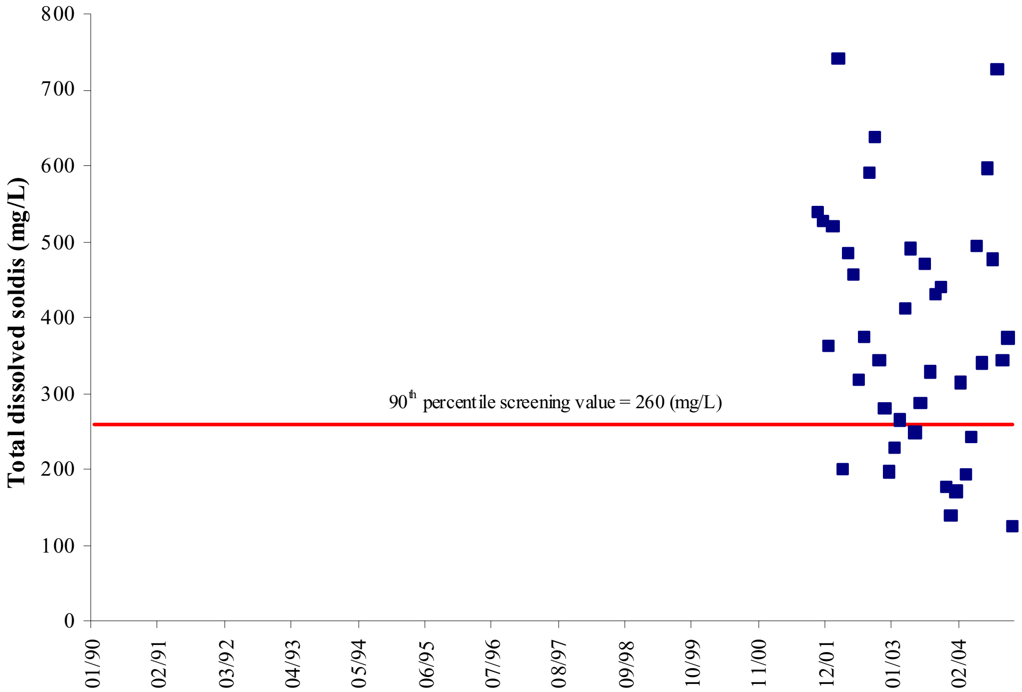

Figure 7.80 TDS concentrations at DMME MPID 4392.

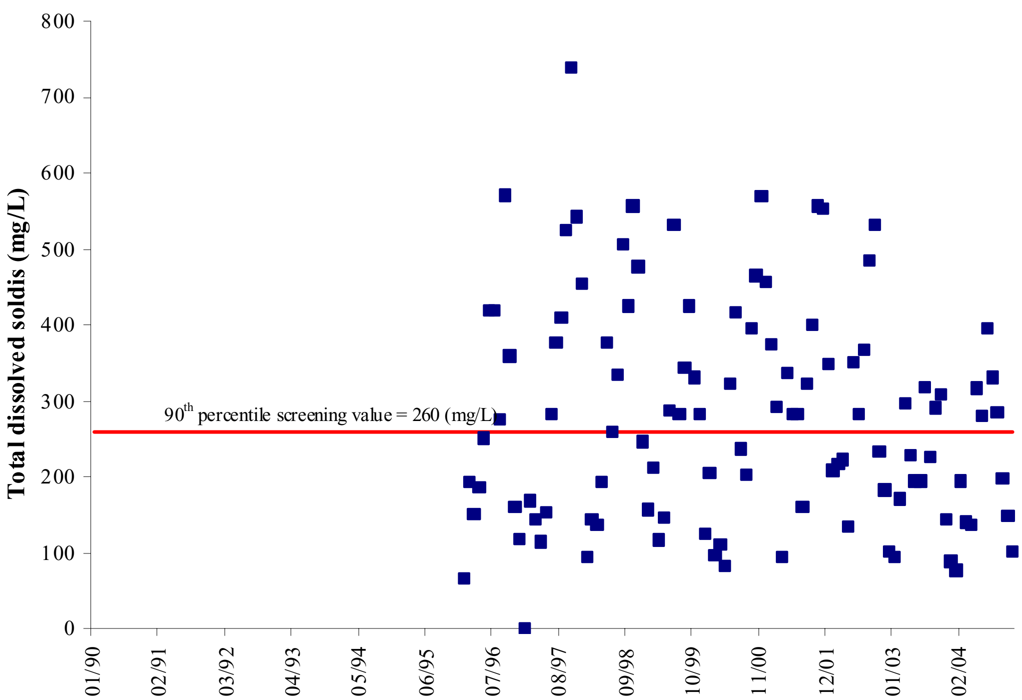

Figure 7.81 TDS concentrations at DMME MPID 6020004.

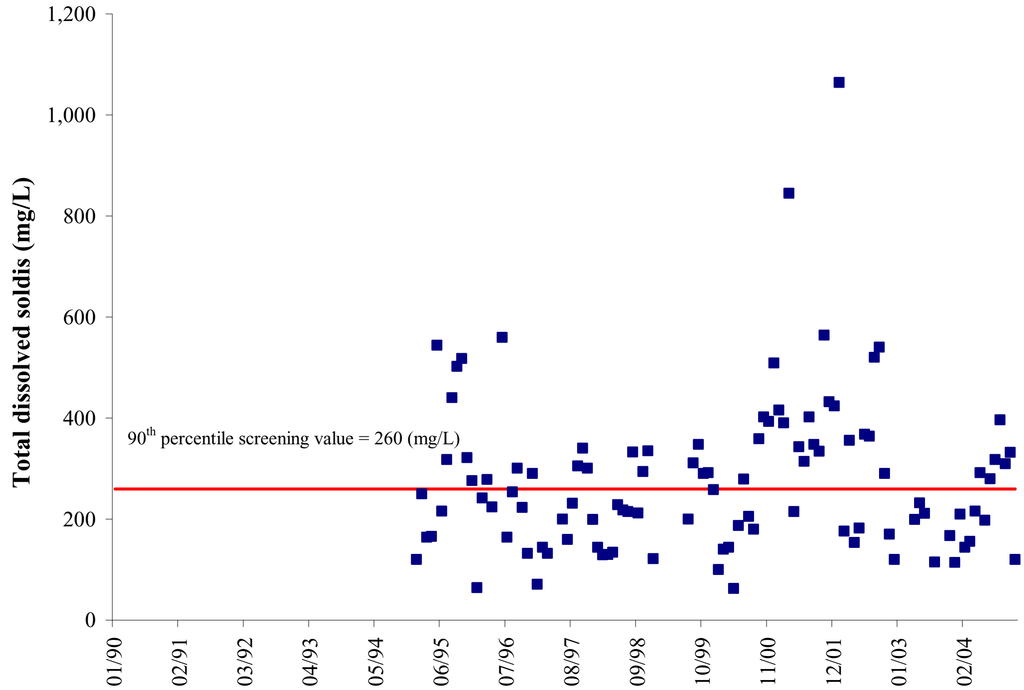

Figure 7.82 TDS concentrations at DMME MPID 6020016.

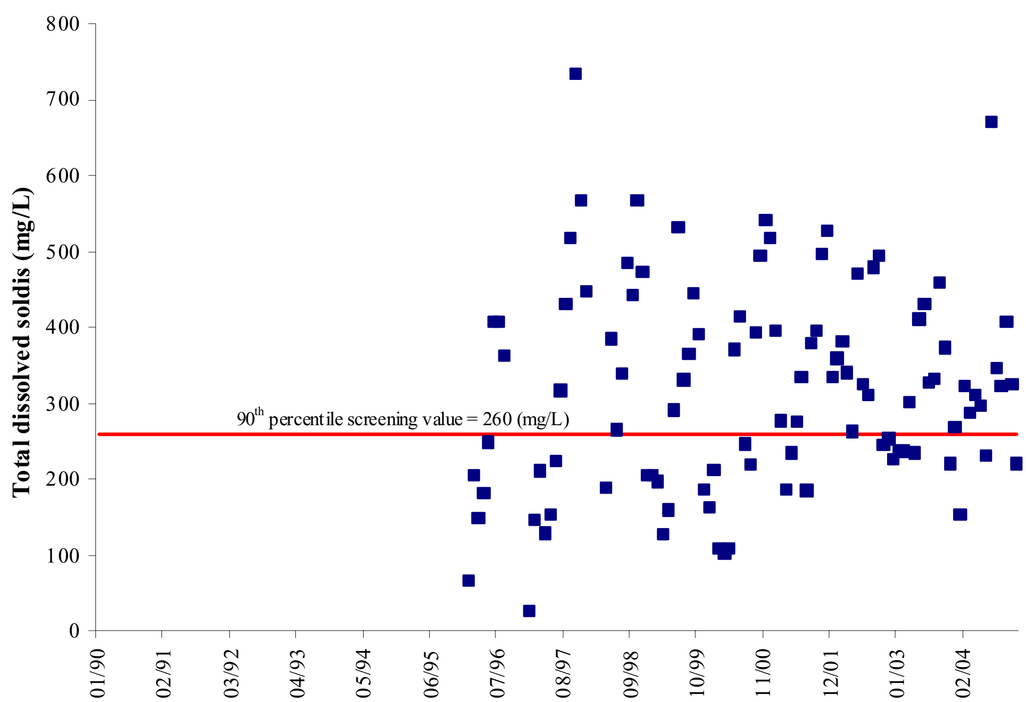

Figure 7.83 TDS concentrations at DMME MPID 6020037.

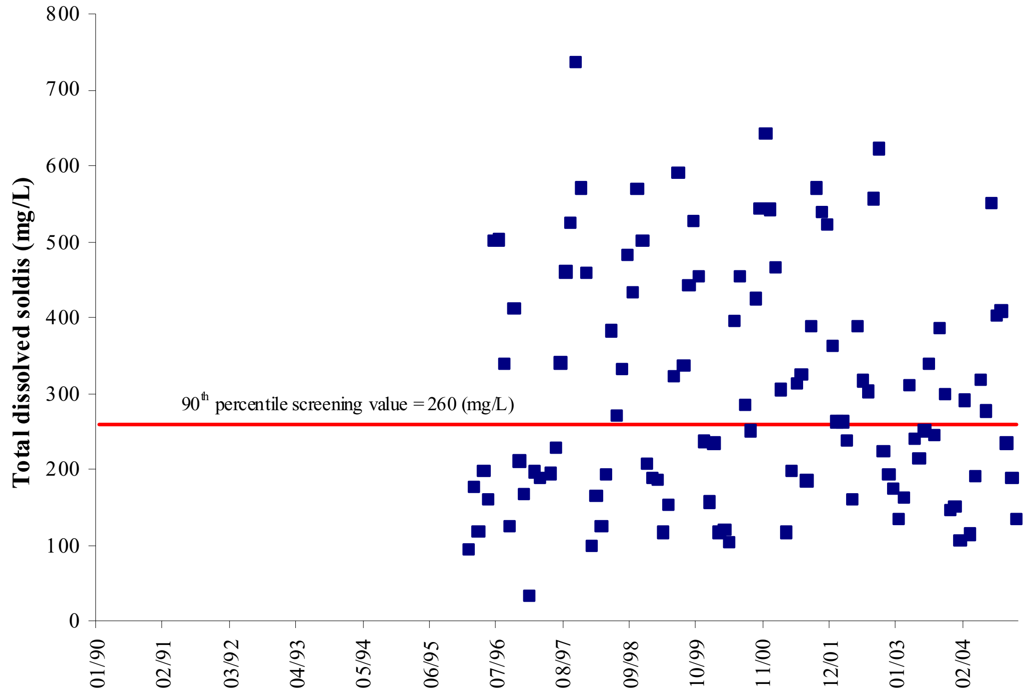

Figure 7.84 TDS concentrations at DMME MPID 6020042.

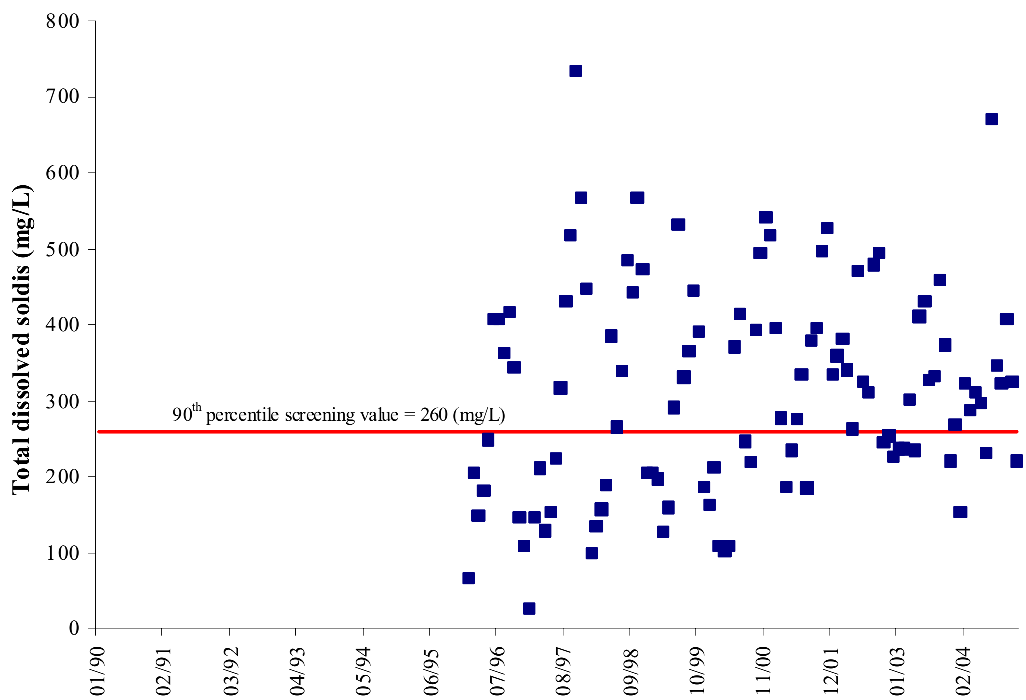

Figure 7.85 TDS concentrations at DMME MPID 6020044.

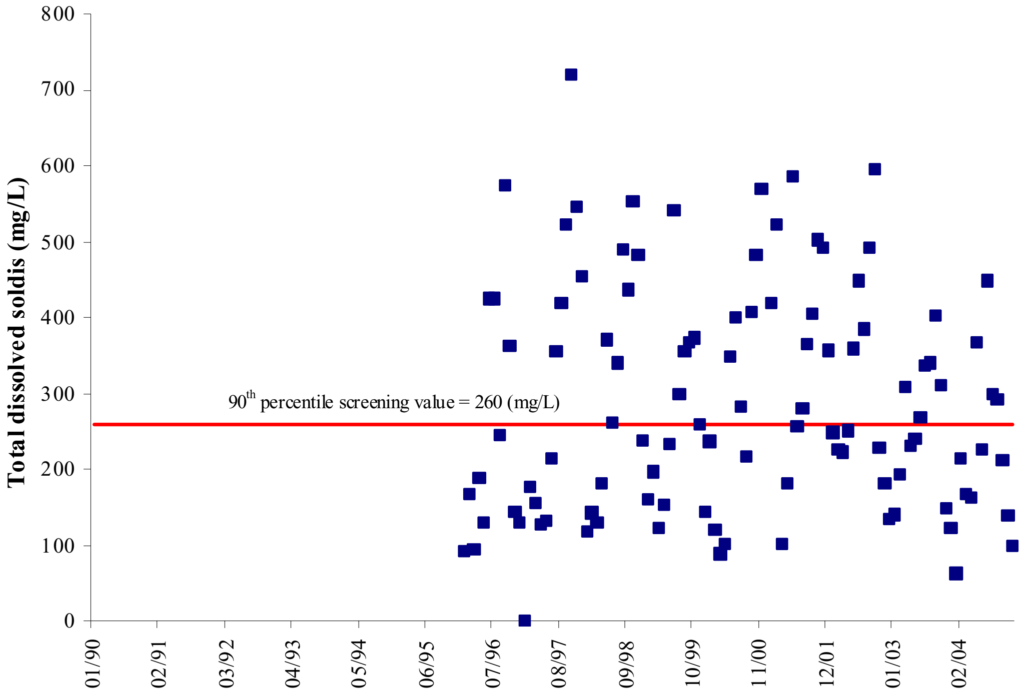

Figure 7.86 TDS concentrations at DMME MPID 6020074.

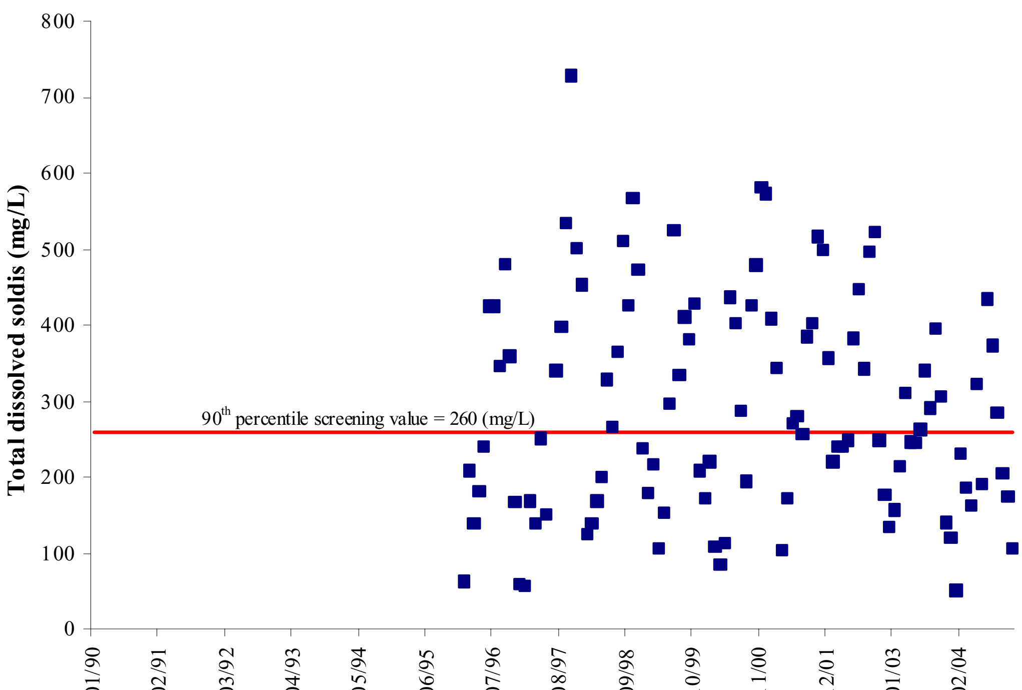

Figure 7.87 TDS concentrations at DMME MPID 6020085.

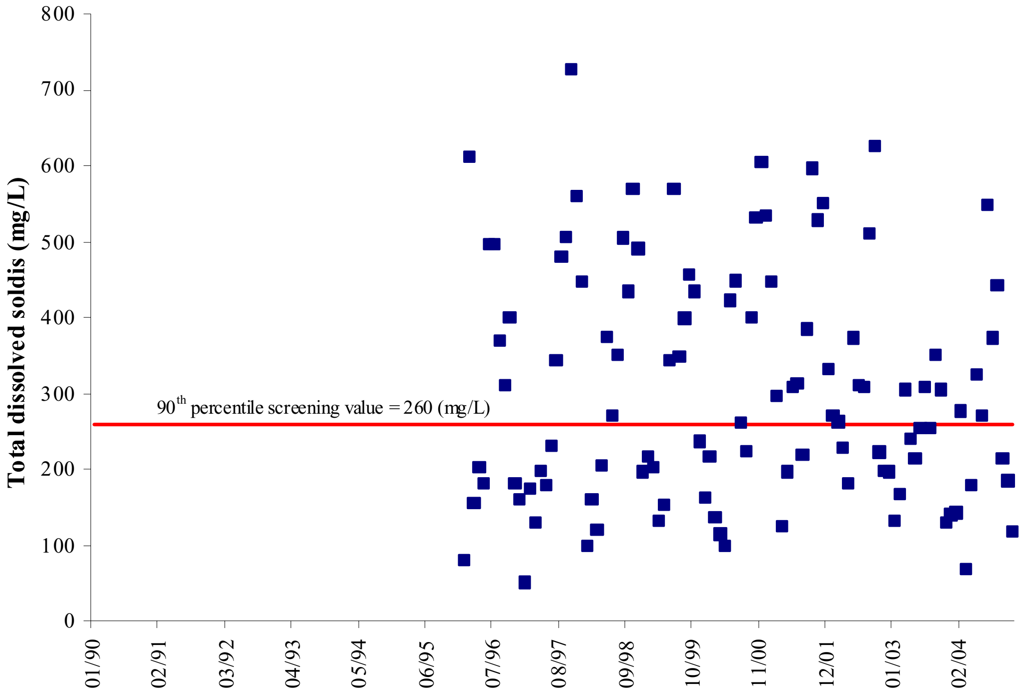

Figure 7.88 TDS concentrations at DMME MPID 6020086.

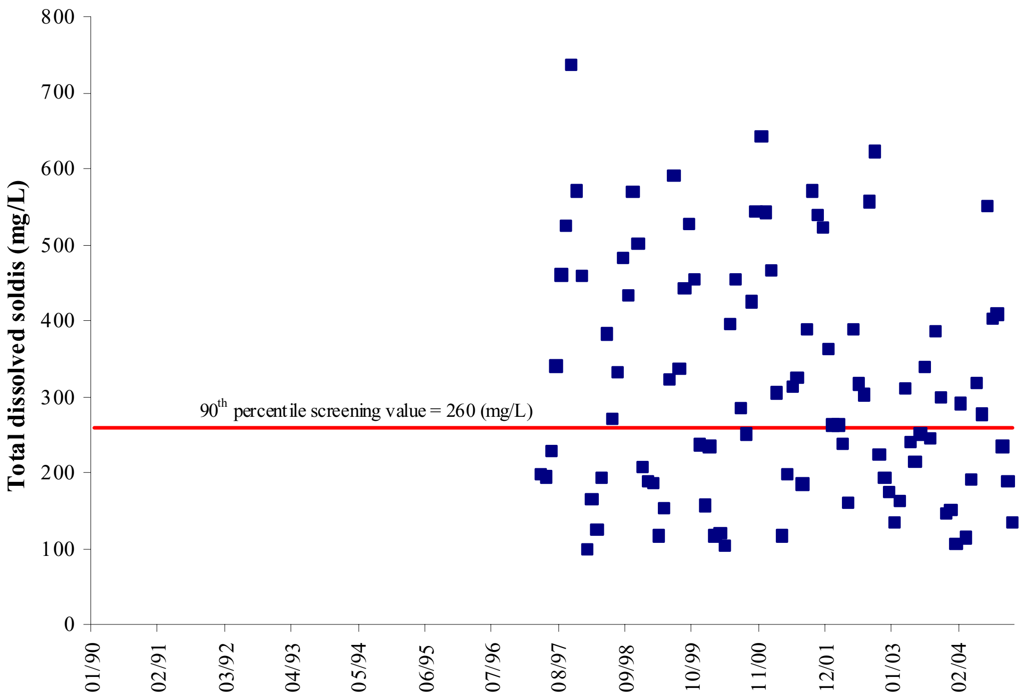

Figure 7.89 TDS concentrations at DMME MPID 6020087.

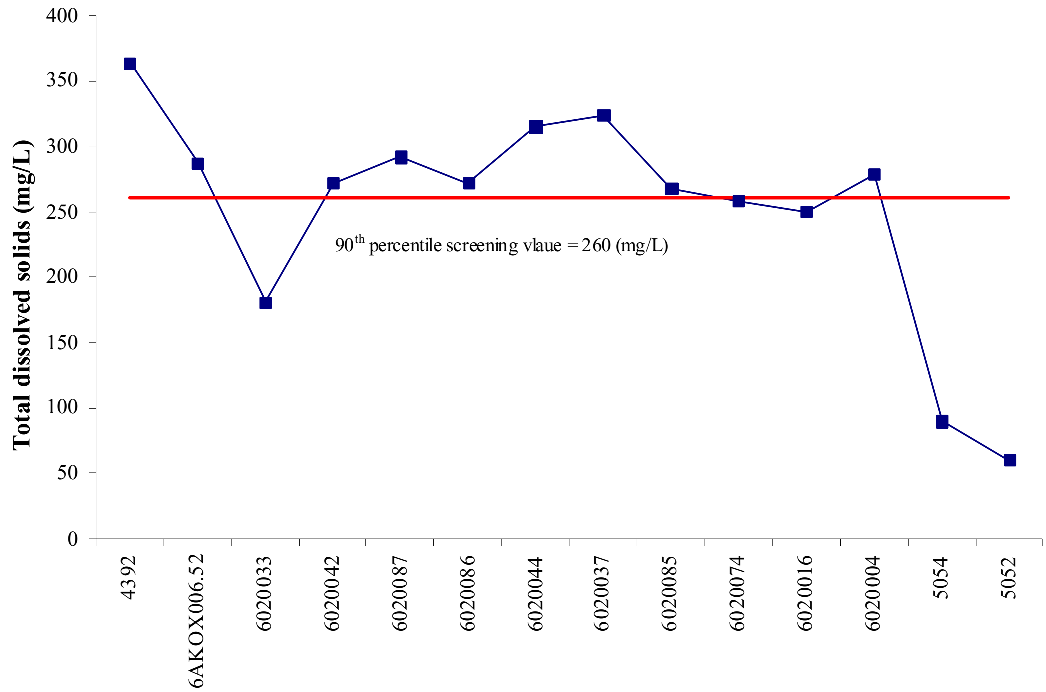

Figure 7.90 Median TDS concentrations in Knox Creek.

TDS concentrations can be harmful to aquatic organisms without causing death. Aquatic organisms balance water and internal ions through a number of different mechanisms. Therefore high concentrations and significant changes in TDS over long periods of time can place a lot of stress on the organisms. The resulting chronic stress affects processes such as growth and reproduction. Sudden large spikes in TDS concentration can be fatal. A study of TDS toxicity in a coal-mining watershed in southeastern Ohio found the lowest observed effect concentration (LOEC) on the test organism *Isonychia bicolor* (a species of Mayfly) was 1,066 mg/L (Kennedy, 2002). The author carefully noted that this concentration was specific to the watershed studied, but noted that similar studies with the same test organism and TDS with varying ionic compositions were toxic between 1,018 and 1,783 mg/L (Kennedy, 2002). Kennedy also cited a study that suggested that aquatic organisms should be able to tolerate TDS concentrations up to 1,000 mg/L; however, the test organism used was *Chironomous tentans*, which is considerably more pollution tolerant than *Isonychia bicolor* (Kennedy, 2002). Research also indicates that the likely mechanism(s) of TDS benthic macroinvertebrate mortality is from gill and internal tissue dehydration, salt accumulation and compromised osmoregulatory function. In fact, the rate of change in TDS concentrations may be more toxic to benthic macroinvertebrates than the TDS alone (Kennedy, 2002).

It is clear from the data available that conductivity and TDS values are too high and there have been very large fluctuations over the sampling period. There is little doubt that the extremely high TDS concentrations often present in Knox Creek are responsible for depressing the sensitive benthic community. Therefore, conductivity and TDS are considered probable stressors. Modeling and subsequent allocations will focus on TDS.

7.5 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on the possible and probable stressors. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month. A seasonal analysis of water chemistry results was conducted using the Mood's Median Test. This test was used to compare median values of water quality in each season.

The results of the Seasonal Kendall Test used to detect long-term trends are shown in Tables 7.4 through 7.18. Knox Creek at MPID stations 6020033, 6020037, and 6020044 showed an overall positive trend for conductivity. The positive trends for conductivity show that the concentration is increasing over time at these stations in Knox Creek. Data at MPID 6020033 shows that Knox Creek has a decreasing trend for TDS. Knox Creek at MPIDs 6020033 and 6084658 shows small positive trends for TSS. Sulfate data at MPIDs 6020033 and 6020044 shows a positive trend in Knox Creek. Knox Creek at MPID 6084617 shows a small negative trend for Manganese. The water quality constituents that have no trends show that the concentrations are stable over time at those stations in Knox Creek.

Table 7.4 Trend Analysis results for MPID 4392.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.5 Trend Analysis results for MPID 6020004.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.6 Trend Analysis results for MPID 6020016.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Manganese, µg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.7 Trend Analysis results for MPID 6020033.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	9.000
Total Dissolved Solids, mg/L	-11.000
Total Suspended Solids, mg/L	1.000
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	16.571

Table 7.8 Trend Analysis results for MPID 6020037.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	12.583
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.9 Trend Analysis results for MPID 6020042.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.10 Trend Analysis results for MPID 6020044.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	15.381
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	8.417

Table 7.11 Trend Analysis results for MPID 6020074.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.12 Trend Analysis results for MPID 6020085.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.13 Trend Analysis results for MPID 6020086.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.14 Trend Analysis results for MPID 6020087.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Sulfate, Total, mg/L	No Trend

Table 7.15 Trend Analysis results for MPID 6084617.

Water Quality Constituent	Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Manganese, µg/L	-0.05

Table 7.16 Trend Analysis results for MPID 6084658.

Water Quality Constituent	Trend
Total Suspended Solids, mg/L	0.520
Iron, Total, mg/L	No Trend
Manganese, µg/L	No Trend

Table 7.17 Trend Analysis results for MPID 6084668.

Water Quality Constituent	Trend
Total Suspended Solids, mg/L	No Trend
Iron, Total, mg/L	No Trend
Manganese, µg/L	No Trend

Table 7.18 Trend Analysis results for station 6AKOX006.52.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Manganese, µg/L	--
Sulfate, Total, mg/L	No Trend
Total Organic Solids	No Trend
Total Organic Suspended Solids	--

"--": insufficient data

The results of the Mood's Median Test for seasonality for water quality data from Knox Creek are shown in Tables 7.19 through 7.51. Values in seasons with the same median group letter are not significantly different from each other at a 95% significance level. For example (Table 7.19), the Spring and Fall are in median group "B" and are not significantly different from each other. In seasons with multiple groups (Fall is in "B" and "C"), the values are the result of the 95% confidence interval for that season overlapping more than one median group. At MPID 602004 (Table 7.19) the conductivity values collected during the winter are statistically different than the values collected in all other seasons; the values from spring are statistically different than values from the summer.

Table 7.19 Summary of Mood's Median Test on Conductivity at MPID 6020004.

Season	Mean	Min	Max	Median Group		
Winter	250.85	130.00	520.00	A		
Spring	394.22	130.00	740.00		B	
Summer	539.96	280.00	849.00			C
Fall	448.15	168.00	916.00		B	C

Table 7.20 Summary of Mood's Median Test on Conductivity at MPID 6020037.

Season	Mean	Min	Max	Median Group	
Winter	315.79	130.00	510.00	A	
Spring	444.93	160.00	740.00	A	B
Summer	574.27	250.00	980.00		B
Fall	525.13	269.00	903.00		B

Table 7.21 Summary of Mood's Median Test on Conductivity at MPID 6020042.

Season	Mean	Min	Max	Median Group	
Winter	280.26	120.00	580.00	A	
Spring	433.85	170.00	830.00	A	B
Summer	619.96	300.00	1020.00		B
Fall	474.78	167.00	899.00		B

Table 7.22 Summary of Mood's Median Test on Conductivity at MPID 6020044.

Season	Mean	Min	Max	Median Group	
Winter	301.70	130.00	510.00	A	
Spring	444.93	160.00	740.00	A	B
Summer	577.81	250.00	980.00		B
Fall	497.67	265.00	903.00		B

Table 7.23 Summary of Mood's Median Test on Conductivity at MPID 6020074.

Season	Mean	Min	Max	Median Group		
Winter	274.15	110.00	610.00	A		
Spring	416.26	160.00	750.00		B	
Summer	569.19	368.00	876.00			C
Fall	450.19	160.00	904.00	A	B	C

Table 7.24 Summary of Mood's Median Test on Conductivity at MPID 6020085.

Season	Mean	Min	Max	Median Group		
Winter	265.15	140.00	470.00	A		
Spring	416.85	150.00	710.00		B	
Summer	575.96	366.00	366.00			C
Fall	468.74	146.00	897.00	A	B	C

Table 7.25 Summary of Mood's Median Test on Conductivity at MPID 6020086.

Season	Mean	Min	Max	Median Group	
Winter	284.67	150.00	560.00	A	
Spring	427.11	160.00	810.00	A	B
Summer	634.00	310.00	1092.00		B
Fall	483.11	189.00	900.00		B

Table 7.26 Summary of Mood's Median Test on Conductivity at MPID 6020087.

Season	Mean	Min	Max	Median Group	
Winter	283.43	140.00	580.00	A	
Spring	435.71	170.00	830.00	A	
Summer	624.96	300.00	1020.00		B
Fall	479.13	167.00	899.00	A	B

Table 7.27 Summary of Mood's Median Test on Conductivity at MPID 6020016.

Season	Mean	Min	Max	Median Group	
Winter	395.92	160.00	1337.00	A	
Spring	424.08	125.00	1157.00	A	B
Summer	561.00	194.00	869.00		B
Fall	516.48	160.00	851.00		B

Table 7.28 Summary of Mood's Median Test on Conductivity at MPID 4392.

Season	Mean	Min	Max	Median Group	
Winter	454.67	255.00	850.00	A	B
Spring	567.11	401.00	782.00	A	B
Summer	752.11	552.00	970.00		B
Fall	447.50	172.00	780.00	A	

Table 7.29 Summary of Mood's Median Test on Conductivity at station 6AKOX006.52.

Season	Mean	Min	Max	Median Group	
Winter	271.0586	148	499.71	A	
Spring	374.2645	144.5	705.4	A	
Summer	585.795	246	854.71		B
Fall	535.1419	212.5	801.83	A	B

Table 7.30 Summary of Mood's Median Test on TDS at MPID 6020004.

Season	Mean	Min	Max	Median Group		
Winter	163.63	2.00	376.00	A		
Spring	262.22	84.00	534.00		B	
Summer	365.81	162.00	572.00			C
Fall	328.96	90.00	740.00	A	B	C

Table 7.31 Summary of Mood's Median Test on TDS at MPID 6020037.

Season	Mean	Min	Max	Median Group	
Winter	219.17	28.00	396.00	A	
Spring	292.89	110.00	534.00	A	B
Summer	385.96	186.00	672.00		B
Fall	383.92	164.00	736.00	A	B

Table 7.32 Summary of Mood's Median Test on TDS at MPID 6020042.

Season	Mean	Min	Max	Median Group		
Winter	184.00	34.00	468.00	A		
Spring	283.77	106.00	592.00		B	
Summer	399.96	126.00	624.00			C
Fall	356.15	738.00	738.00	A	B	C

Table 7.33 Summary of Mood's Median Test on TDS at MPID 6020044.

Season	Mean	Min	Max	Median Group	
Winter	209.41	28.00	396.00	A	
Spring	292.89	110.00	534.00		B
Summer	387.15	186.00	672.00		B
Fall	363.63	110.00	736.00		B

Table 7.34 Summary of Mood's Median Test on TDS at MPID 6020074.

Season	Mean	Min	Max	Median Group	
Winter	180.22	2.00	524.00	A	
Spring	274.81	102.00	588.00	A	B
Summer	385.56	218.00	596.00		B
Fall	323.96	100.00	722.00	A	B

Table 7.35 Summary of Mood's Median Test on TDS at MPID 6020085.

Season	Mean	Min	Max	Median Group		
Winter	180.30	52.00	410.00	A		
Spring	278.31	114.00	526.00		B	
Summer	385.96	196.00	536.00			C
Fall	333.63	60.00	730.00	A	B	C

Table 7.36 Summary of Mood's Median Test on TDS at MPID 6020086.

Season	Mean	Min	Max	Median Group	
Winter	198.59	52.00	614.00	A	
Spring	280.59	100.00	570.00	A	
Summer	401.74	220.00	628.00		B
Fall	348.07	120.00	728.00	A	B

Table 7.37 Summary of Mood's Median Test on TDS at MPID 6020087.

Season	Mean	Min	Max	Median Group	
Winter	197.71	100.00	468.00	A	
Spring	279.75	106.00	592.00	A	
Summer	409.54	186.00	624.00		B
Fall	367.58	136.00	738.00	A	B

Table 7.38 Summary of Mood's Median Test on TDS at MPID 6020016.

Season	Mean	Min	Max	Median Group	
Winter	250.38	64.00	1064.00	A	B
Spring	247.63	63.00	560.00	A	
Summer	309.11	115.00	540.00		B
Fall	294.45	114.00	564.00		B

Table 7.39 Summary of Mood's Median Test on TDS at MPID 4392.

Season	Mean	Min	Max	Median Group	
Winter	339.78	172.00	742.00	A	B
Spring	375.11	244.00	496.00	A	B
Summer	516.22	330.00	728.00		B
Fall	322.00	126.00	540.00	A	

Table 7.40 Summary of Mood's Median Test on TDS at station 6AKOX006.52.

Season	Mean	Min	Max	Median Group	
Winter	176.5833	119	336	A	
Spring	257.0769	64	508	A	B
Summer	405.4118	164	591		B
Fall	385.2222	140	561	A	B

Table 7.41 Summary of Mood's Median Test on Sulfate at MPID 6020004.

Season	Mean	Min	Max	Median Group	
Winter	37.83	20.00	71.00	A	
Spring	45.28	8.00	87.00	A	
Summer	76.06	36.00	136.00		B
Fall	73.67	23.00	110.00		B

Table 7.42 Summary of Mood's Median Test on Sulfate at MPID 6020037.

Season	Mean	Min	Max	Median Group	
Winter	122.33	20.00	272.00	A	
Spring	156.00	52.00	284.00	A	B
Summer	196.96	100.00	339.00		B
Fall	194.17	66.00	350.00		B

Table 7.43 Summary of Mood's Median Test on Sulfate at MPID 6020042.

Season	Mean	Min	Max	Median Group	
Winter	94.26	4.00	304.00	A	
Spring	152.96	57.00	270.00	A	B
Summer	209.41	95.00	377.00		B
Fall	166.44	40.00	336.00	A	B

Table 7.44 Summary of Mood's Median Test on Sulfate at MPID 6020044.

Season	Mean	Min	Max	Median Group	
Winter	107.74	2.00	272.00	A	
Spring	156.00	52.00	284.00	A	B
Summer	194.48	100.00	339.00		B
Fall	182.22	50.00	350.00		B

Table 7.45 Summary of Mood's Median Test on Sulfate at MPID 6020074.

Season	Mean	Min	Max	Median Group	
Winter	97.48	15.00	263.00	A	
Spring	140.30	50.00	279.00	A	B
Summer	184.85	59.00	322.00		B
Fall	141.46	33.00	302.00	A	B

Table 7.46 Summary of Mood's Median Test on Sulfate at MPID 6020085.

Season	Mean	Min	Max	Median Group	
Winter	93.63	15.00	244.00	A	
Spring	144.19	18.00	282.00	A	B
Summer	190.63	60.00	322.00		B
Fall	159.81	20.00	340.00	A	B

Table 7.47 Summary of Mood's Median Test on Sulfate at MPID 6020086.

Season	Mean	Min	Max	Median Group	
Winter	93.56	6.00	279.00	A	
Spring	145.96	50.00	258.00	A	B
Summer	202.93	85.00	374.00		B
Fall	163.41	20.00	331.00	A	B

Table 7.48 Summary of Mood's Median Test on Sulfate at MPID 6020087.

Season	Mean	Min	Max	Median Group	
Winter	100.52	34.00	304.00	A	
Spring	152.33	57.00	270.00	A	B
Summer	216.79	111.00	377.00		B
Fall	176.83	42.00	336.00	A	B

Table 7.49 Summary of Mood's Median Test on Sulfate at station 6AKOX006.52.

Season	Mean	Min	Max	Median Group	
Winter	84.20	20.30	131.00	A	
Spring	127.43	50.50	232.00	A	
Summer	193.12	65.40	269.00		B
Fall	213.69	63.20	415.00		B

Table 7.50 Summary of Mood's Median Test on Total Organic Solids at station 6AKOX006.52.

Season	Mean	Min	Max	Median Group	
Winter	37.83	20.00	71.00	A	
Spring	45.28	8.00	87.00	A	
Summer	76.06	36.00	136.00		B
Fall	73.67	23.00	110.00		B

Table 7.51 Summary of Mood's Median Test on Manganese at MPID 6084668.

Season	Mean	Min	Max	Median Group	
Winter	0.41	0.10	1.40		B
Spring	0.26	0.10	0.40	A	B
Summer	0.15	0.10	0.40	A	
Fall	0.16	0.10	0.40	A	

8. TMDL ENDPOINT: STRESSOR IDENTIFICATION – PAWPAW CREEK

8.1 Stressor Identification

Pawpaw Creek begins in Kentucky and flows east until it merges with Knox Creek before the VA/Kentucky state line. The stream is approximately 4.52 miles long in Virginia and is a second order stream. The impaired section begins at the state line and extends to the Knox Creek confluence for a total length of 4.52 stream miles. The Pawpaw Creek Watershed is 97% forest, <1% crop, 1% water, 2% active mining, <1% residential and <1% pasture.

For a water quality constituent without an established standard, criteria, or screening value, a 90th percentile screening value was used. The 90th percentile screening values were calculated from 14 monitoring stations in southwest Virginia on first and second order streams that were used as benthic reference stations or were otherwise found not to have a benthic impairment based on the most recent sampling results. The 90th percentile screening values were used to develop a list of possible stressors to the benthic community in Pawpaw Creek. For a water quality constituent, or parameter, to be named a probable stressor, additional information was required. Graphs are shown for parameters that exceeded the screening value in more than 10% of the samples collected within the impaired segment or if the parameter had extreme values. Median values are shown if a parameter does not exceed the water quality standard, screening value, 90th percentile screening value, or does not have excessive values. Data for parameters with more than one but less than nine data points can be found summarized in section 6.5.1. The presence of nine values was selected as a cutoff in order to avoid using data from stations that were not sampled during different seasons of the year or different flow regimes in Pawpaw Creek. The VADEQ only collected data once at 6APPW000.49, retrieving only field parameters.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000b) was used to separately identify the most probable stressor(s) for Pawpaw Creek. A list of candidate causes was developed from published literature, VADEQ, and DMME staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Land use data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, low dissolved oxygen, pH, metals, conductivity/total dissolved solids and temperature.

The results of the stressor analysis for Pawpaw Creek are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors. Non-stressors are listed in Table 8.1.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors. Possible stressors are listed in Table 8.2
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s). Probable stressors are listed in Table 8.3.

8.2 Non-Stressors

Table 8.1 Non-Stressors in Pawpaw Creek.

Parameter	Location in Document
Low dissolved oxygen	section 8.2.1
Toxics	section 8.2.2
Metals (except sediment iron, total iron, and total manganese)	section 8.2.3

There is always a possibility that conditions in the watershed, available data, and the understanding of the natural processes change more than anticipated by the TMDL. If additional monitoring shows that different most probable stressor(s) exist or water quality target(s) are protective of water quality standards, then the Commonwealth will make use of the option to refine the TMDLs for re-submittal to EPA for approval.

8.2.1 Low Dissolved Oxygen

Dissolved oxygen (DO) was measured once at VADEQ monitoring station 6APPW000.49 in August 2004; the measured concentration (7.38 mg/L) was well above the instantaneous water quality standard of 4.0 mg/L. Dissolved oxygen samples were collected just before sunrise (6:10 am) and just after sunrise (7:38 am) on August 5, 2004 to determine if dissolved oxygen concentrations remained above water quality standards during the night. Oxygen demand is highest during the early morning hours during the summer months and can this can be a time when water quality standard violations occur. The measurements were 7.25 and 7.38 mg/L respectively indicating that dissolved oxygen concentrations remain well above the water quality standards even during the critical time periods just before daylight.

Dissolved oxygen was not measured at the DMME MPID monitoring sites. Low dissolved oxygen concentrations are considered a non-stressor.

8.2.2 Toxics

A toxicity sample was collected by VADEQ in November 2004 from Pawpaw Creek near Kelsa, Virginia and analyzed for possible toxicity by the USEPA Region III laboratory at Wheeling, West Virginia. No toxic effects were observed based on the bioassay results.

8.2.3 Metals

The VADEQ collected sediment metals data at 6APPW000.49 in 2004. Sediment values for chromium, copper, lead, nickel, and zinc were all below the Probable Effect Concentration (PEC) established for the metals (McDonald, 2000). Therefore, these metals are considered non-stressors.

8.3 Possible Stressors

Table 8.2 Possible Stressors in Pawpaw Creek.

Parameter	Location in Document
Temperature	section 8.3.1
pH	section 8.3.2
Metals (Sediment iron, total iron, and total manganese)	section 8.3.3

8.3.1 Temperature

The maximum temperature standard for Pawpaw Creek is 31.0°C. The maximum temperature recorded at the VADEQ monitoring station on Pawpaw Creek was 21.12°C in August 2004. The maximum temperature recorded at the DMME MPIDs was 32.0°C at MPID 6020159 in September 1999 (Figure 8.1). Median temperature measurements are shown in Figure 8.2. Temperature standard violations are neither persistent nor extreme; therefore, temperature is considered a possible stressor.

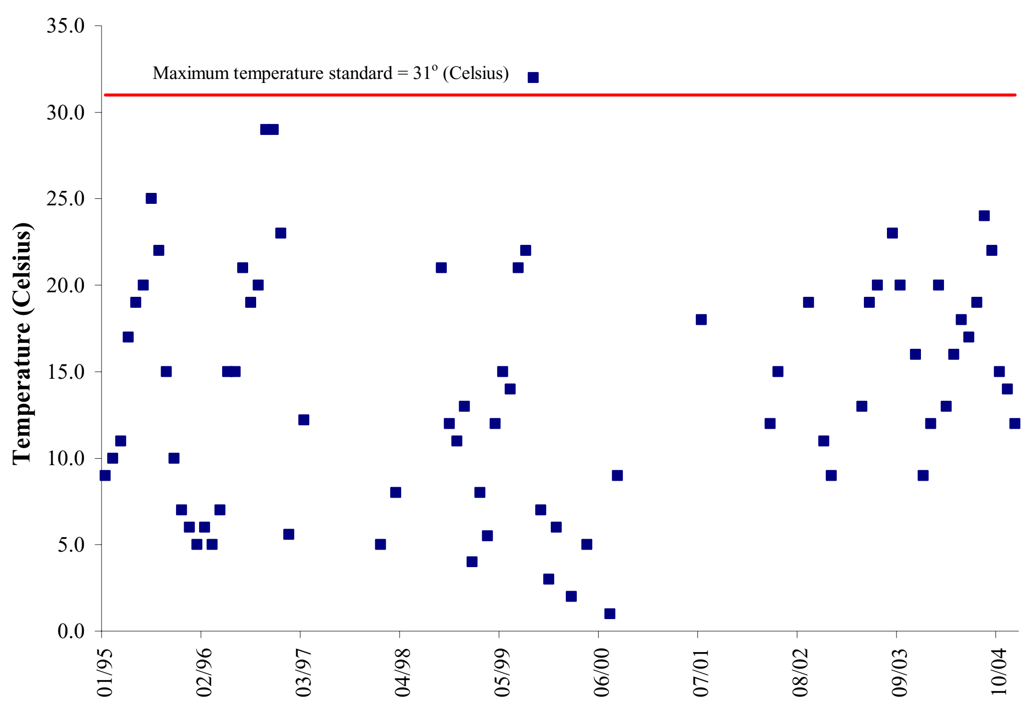

Figure 8.1 Temperature measurements at DMME MPID 6020159.

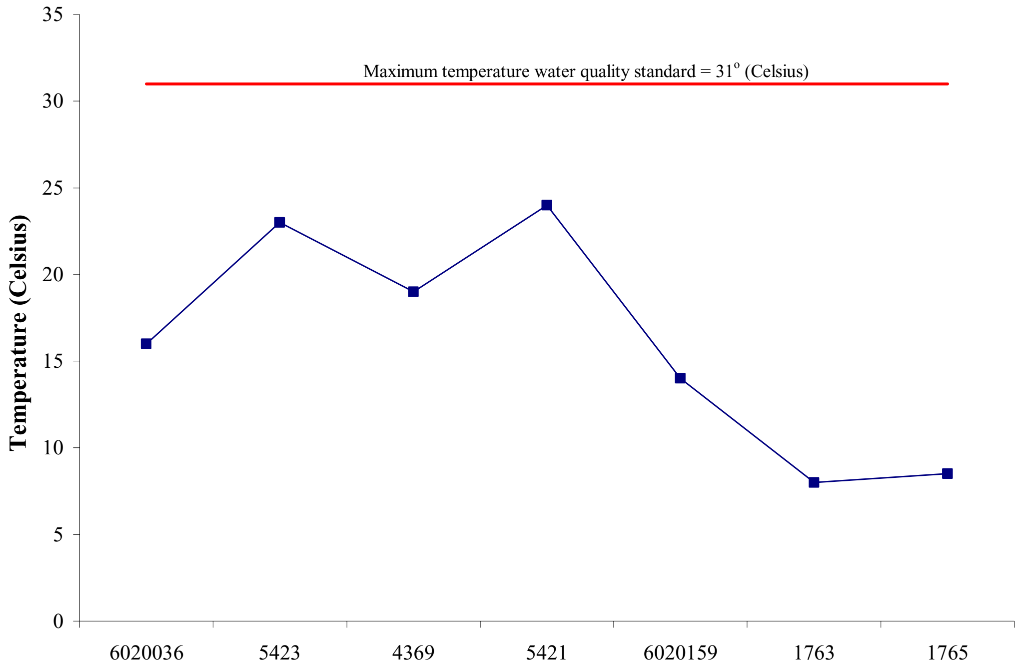

Figure 8.2 Median temperature measurements at DMME MPIDs on Pawpaw Creek.

8.3.2 pH

Field pH was measured at VADEQ monitoring station 6APPW000.49 in August 2004 (8.03 mg/L). It was within the minimum and maximum water quality standard range of 6.0 to 9.0 std units. In March and April 2002, field pH values of 9.6 and 9.5 were measured at MPID 1763 (Figure 8.3) and at MPID 1765 (Figure 8.4) values of 10.4 and 9.6 were measured. In addition, a single high value of 9.05 was measured in March of 1997 at MPID 6020159 (Figure 8.5). Medians for all the DMME MPID sites on Pawpaw Creek are shown in (Figure 8.6). High values were measured at three DMME MPID sites but values above the maximum standard were not chronic or persistent. Because high pH values have occurred in Pawpaw Creek, but do not appear to be persistent or chronic, high pH is considered a possible stressor.

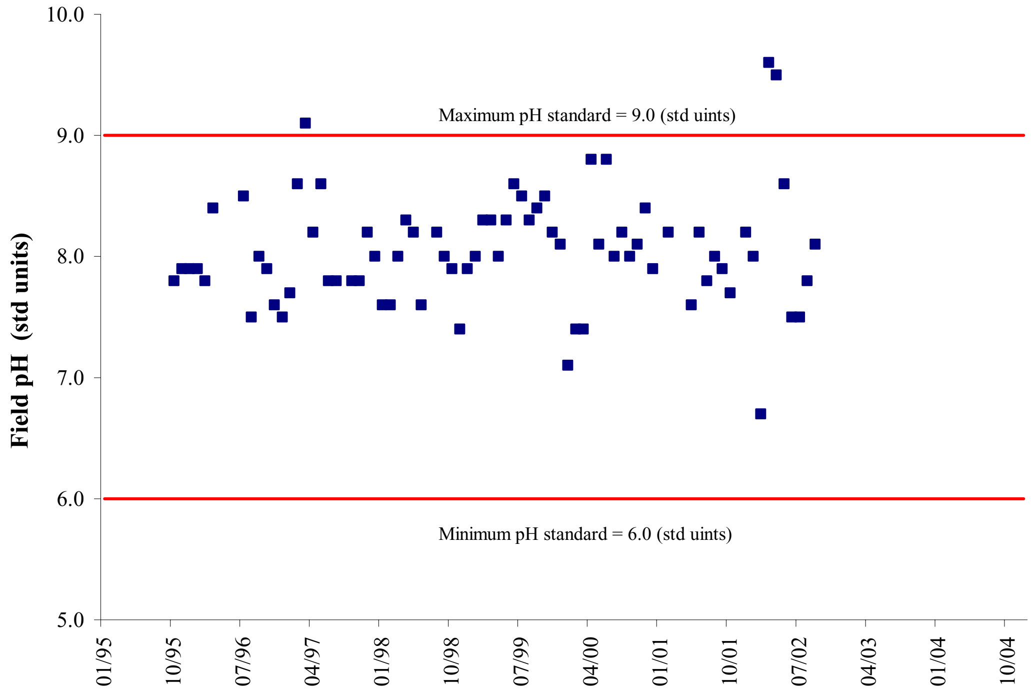

Figure 8.3 Field pH values at DMME MPID 1763.

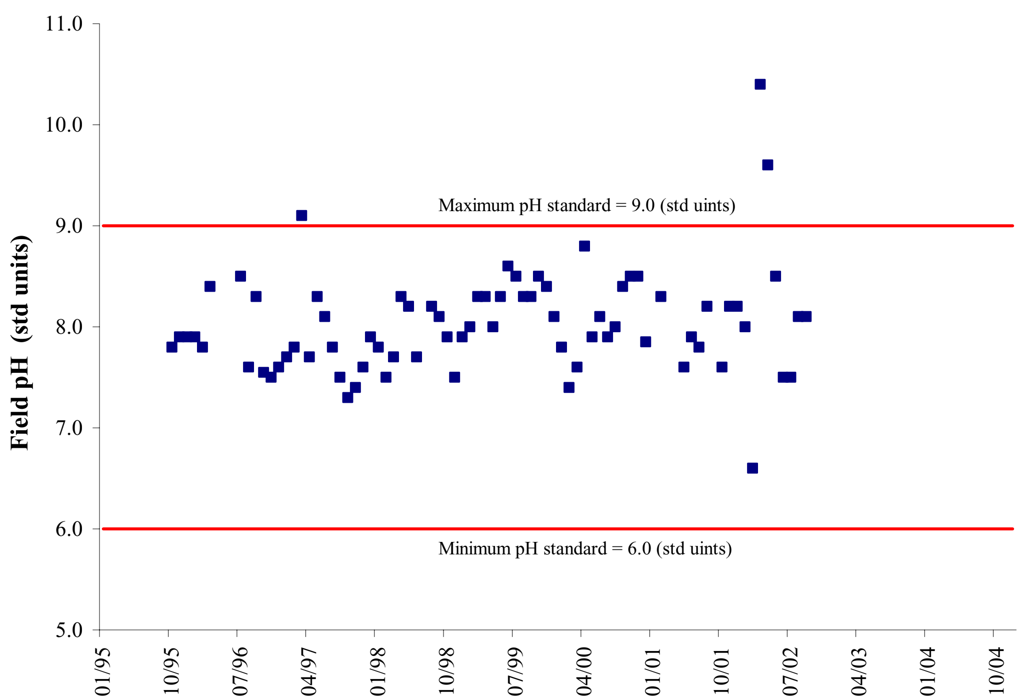

Figure 8.4 Field pH values at DMME MPID 1765.

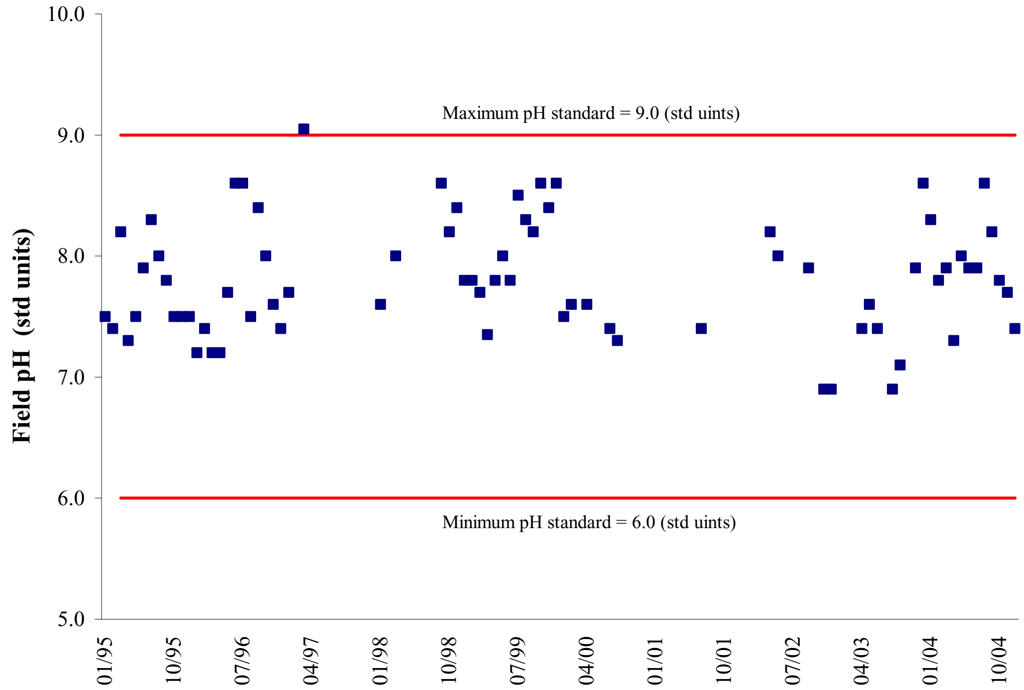

Figure 8.5 Field pH values at DMME MPID 6020159.

Figure 8.6 Median field pH values at DMME MPIDs on Pawpaw Creek.

8.3.3 Metals (Sediment iron, total iron and total manganese)

Total iron and total manganese were collected at all of the DMME MPIDs on Pawpaw Creek. Neither Virginia nor the EPA has a water quality standard for total iron. West Virginia has a water quality standard of 1.5 mg/L for total iron, which was used as a comparison value for this analysis. Samples from Pawpaw Creek did not exceed the total iron comparison value more than 10% of the time at any of the DMME MPID sites. There were extreme values at two DMME MPIDs, 10.40 mg/L at MPID 1763 and 25.4 mg/L at MPID 1765 (Figures 8.7 and 8.8). Median total iron concentrations are shown in Figure 8.9. Available literature suggests that the main problem with high iron concentrations occurs when the iron precipitates out of solution, settles to the streambed, and covers up habitat, and/or smother organisms (Soucek, 2001). There have been no reports of this in Pawpaw Creek.

The 90th percentile screening value for total manganese was 0.06 mg/L; however, 0.1 mg/L was the minimum detection level for the DMME MPID data, therefore 0.1 mg/L was used as the screening value. Pawpaw Creek had more than 10% of the total manganese samples collected exceed the screening value at four DMME MPIDs (Figures 8.10 through 8.13). Median total manganese concentrations are shown in Figure 8.14. When present in extremely high values a yellow precipitate may be present on the streambed, but this has not been observed in Pawpaw Creek. Total iron and total manganese are considered possible stressors.

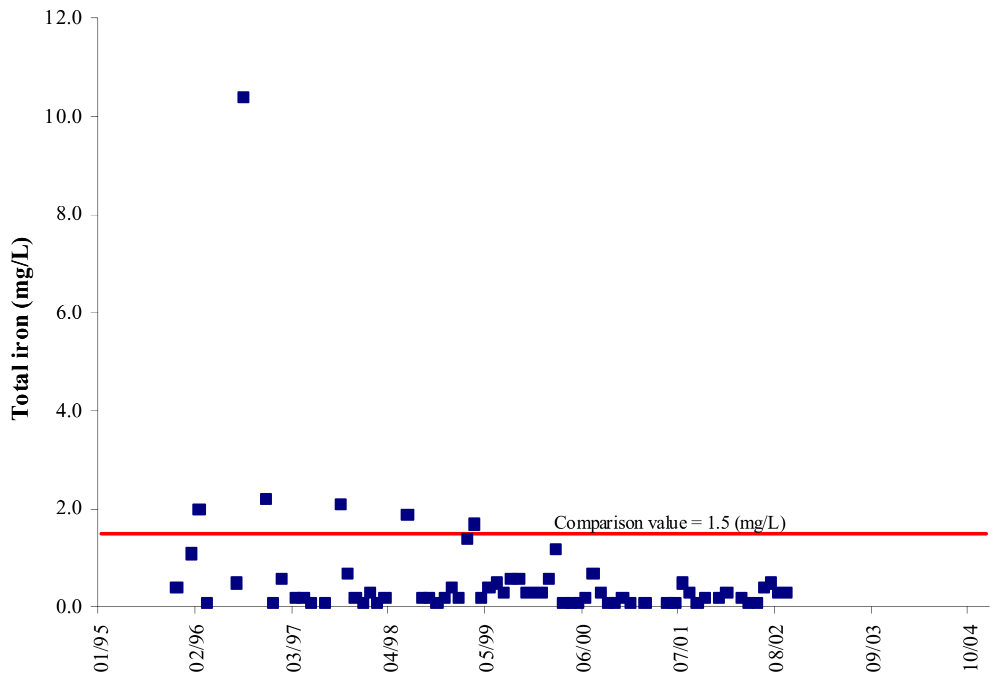

Figure 8.7 Total iron concentrations at DMME MPID 1763 on Pawpaw Creek.

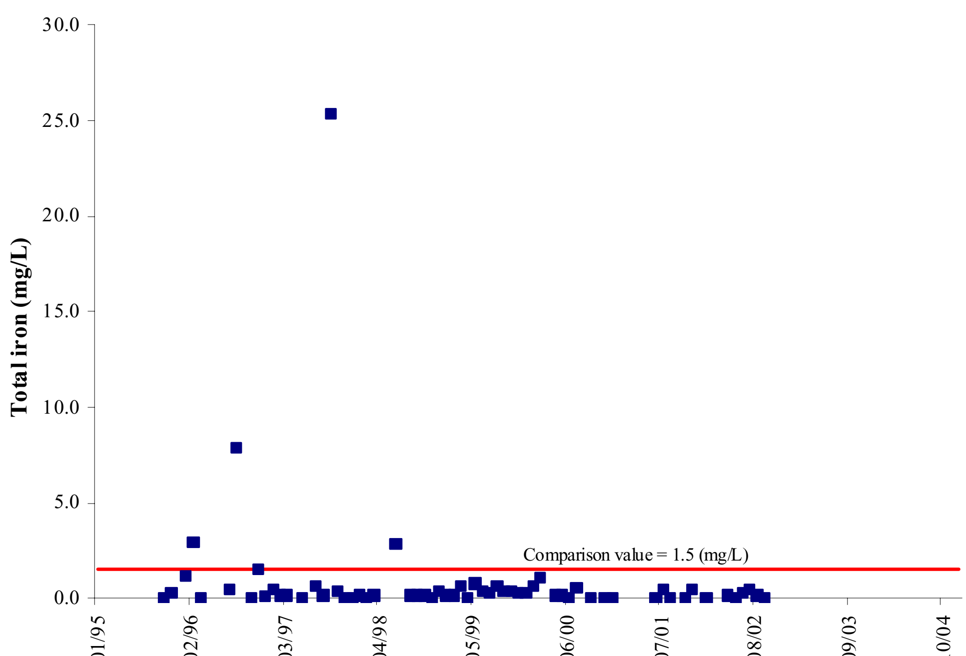

Figure 8.8 Total iron concentrations at DMME MPID 1765 on Pawpaw Creek.

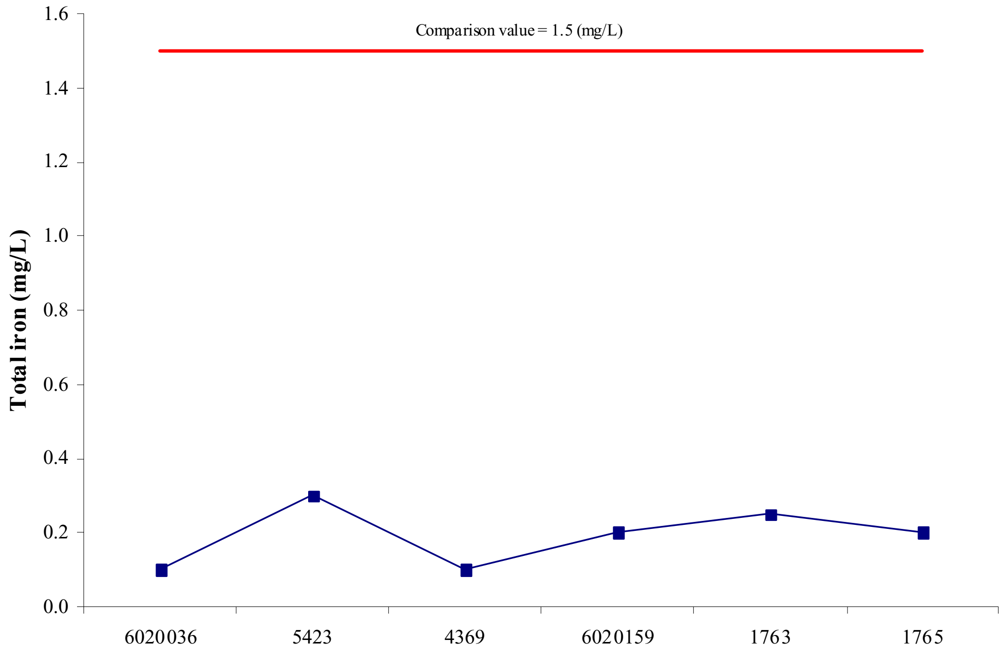

Figure 8.9 Median total iron concentrations at DMME MPIDs on Pawpaw Creek.

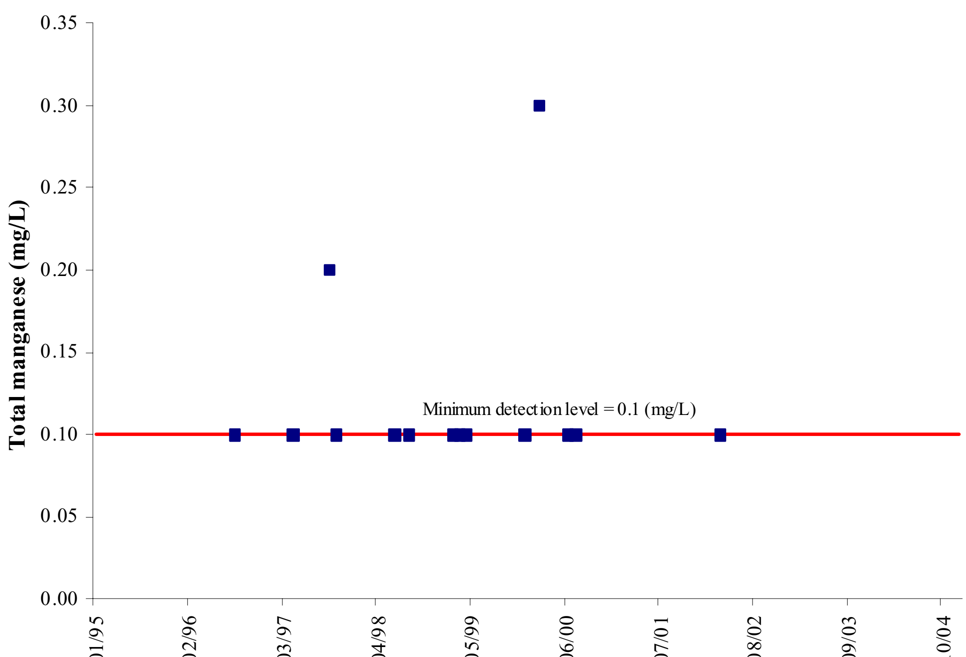

Figure 8.10 Total manganese concentrations at DMME MPID 1763 on Pawpaw Creek.

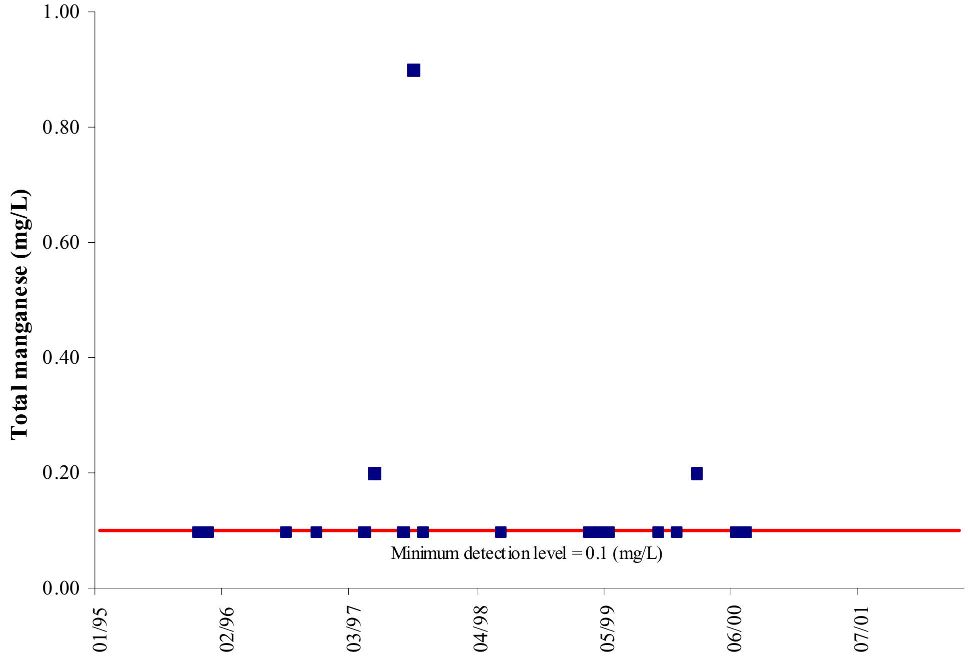

Figure 8.11 Total manganese concentrations at DMME MPID 1765 on Pawpaw Creek.

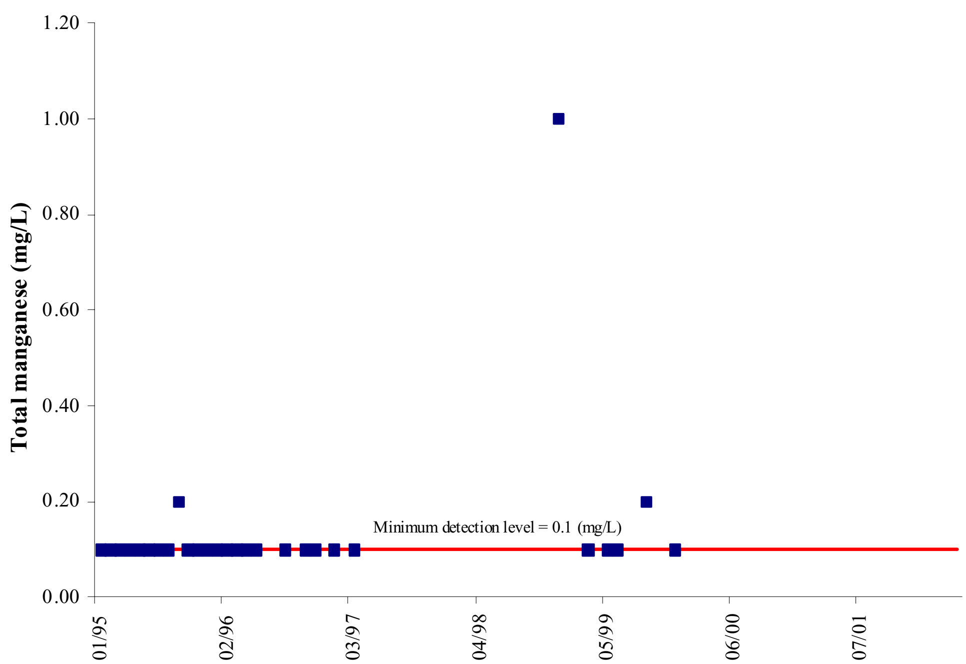

Figure 8.12 Total manganese concentrations at DMME MPID 6020159 on Pawpaw Creek.

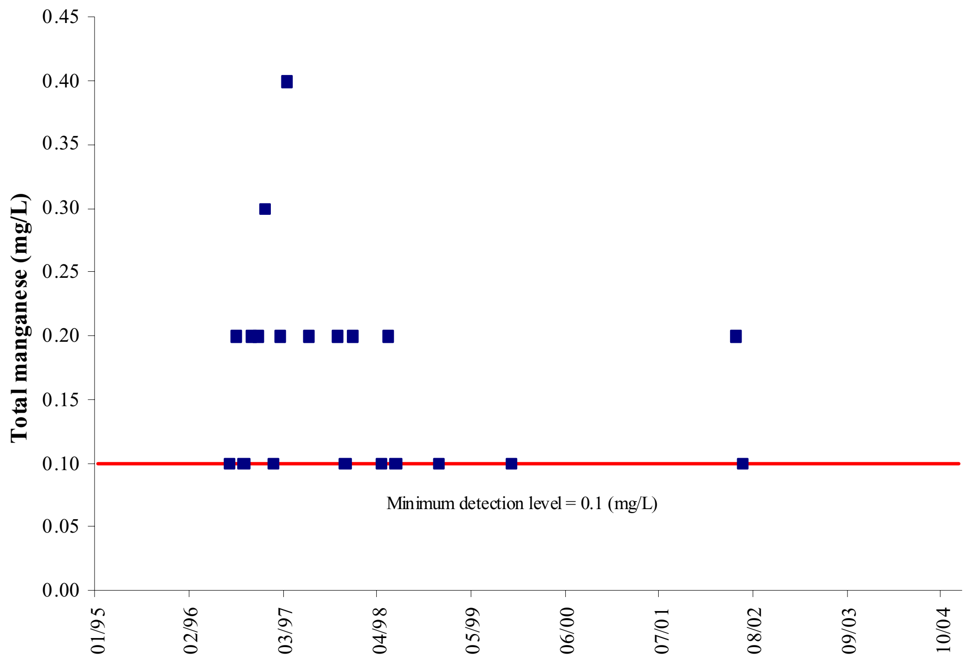

Figure 8.13 Total manganese concentrations at DMME MPID 6020036 on Pawpaw Creek.

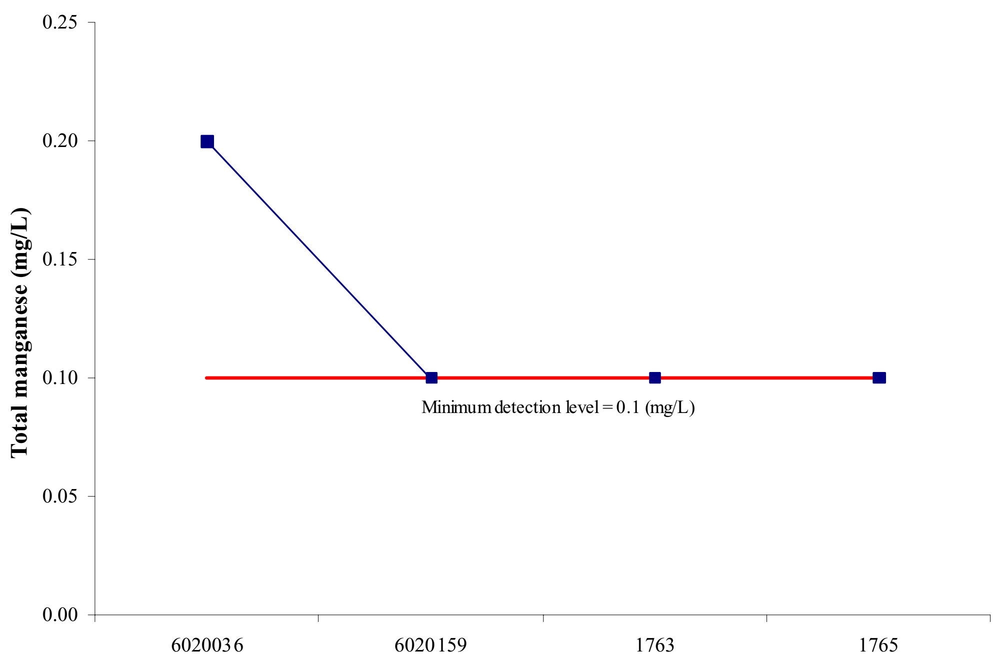

Figure 8.14 Median total manganese concentrations at DMME MPIDs on Pawpaw Creek.

8.4 Probable Stressors

Table 8.3 Probable stressors in Pawpaw Creek.

Parameter	Location in Document
Sediment	section 8.4.1
Conductivity/Total dissolved solids (TDS)	section 8.4.2

8.4.1 Sediment

Only one set of biological habitat scores collected in the Spring 2005 were available for this study. The pool sediment and bank stability metrics were in the marginal range. Total suspended solids (TSS) concentrations exceeded the 90th percentile screening value (20 mg/L) in more than 10% of the samples collected at all seven DMME MPID monitoring sites and there were several extreme values reported (Figures 8.15 through 8.21). Figure 8.22 shows the median concentrations for all seven sites. Based on the persistent and extremely high TSS concentrations and the marginal habitat score for pool sediment, sediment is considered a benthic stressor.

Table 8.4 Total suspended solids statistics for six DMME MPID monitoring sites.

MPID	Average	Maximum	N*
1763	42.6	1,108.0	57
1765	39.7	1,136.0	61
4369	13.14	39.0	36
5421	129.0	886.0	9
5423	95.0	508.0	9
6020159	31.8	584.0	63
6020036	19.8	165.0	104

* N = Number of samples

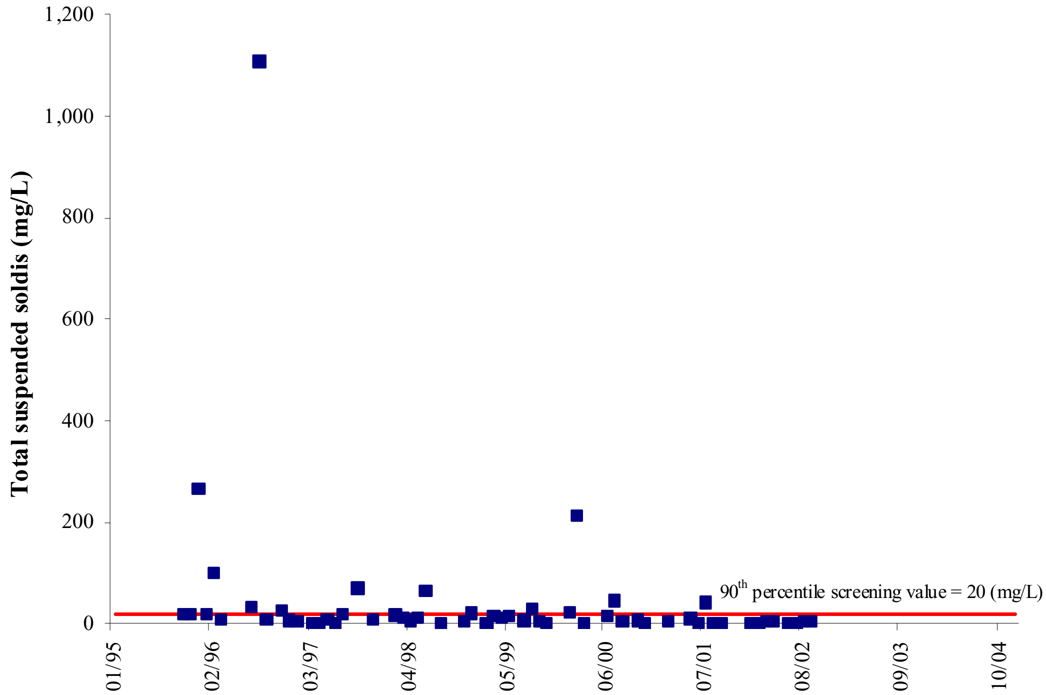

Figure 8.15 TSS concentrations at MPID 1763.

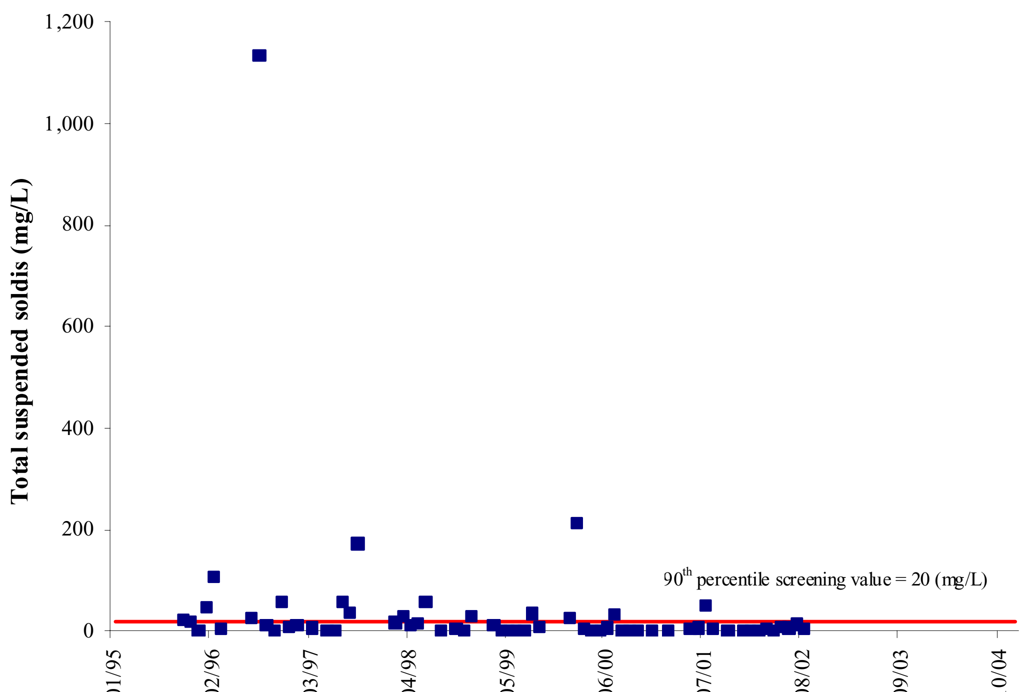

Figure 8.16 TSS concentrations at MPID 1765.

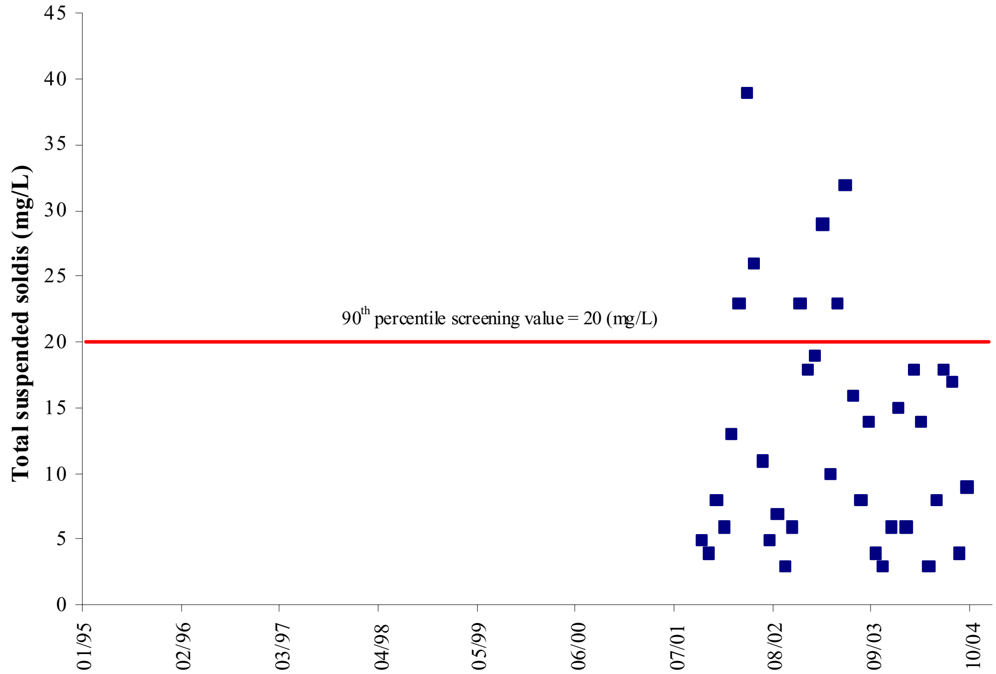

Figure 8.17 TSS concentrations at MPID 4369.

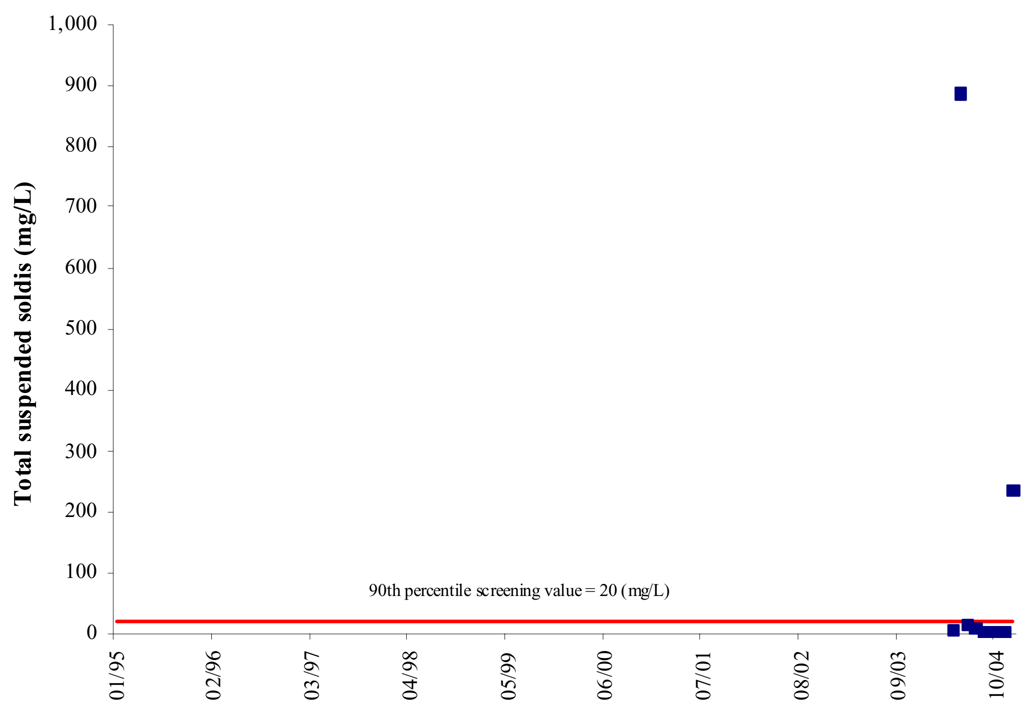

Figure 8.18 TSS concentrations at MPID 5421.

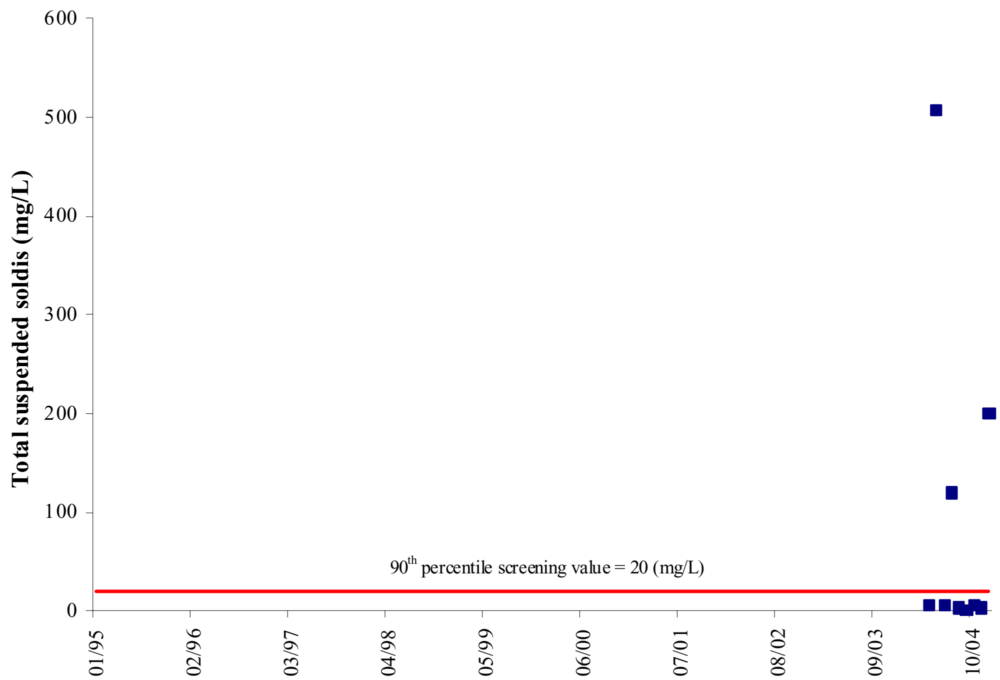

Figure 8.19 TSS concentrations at MPID 5423.

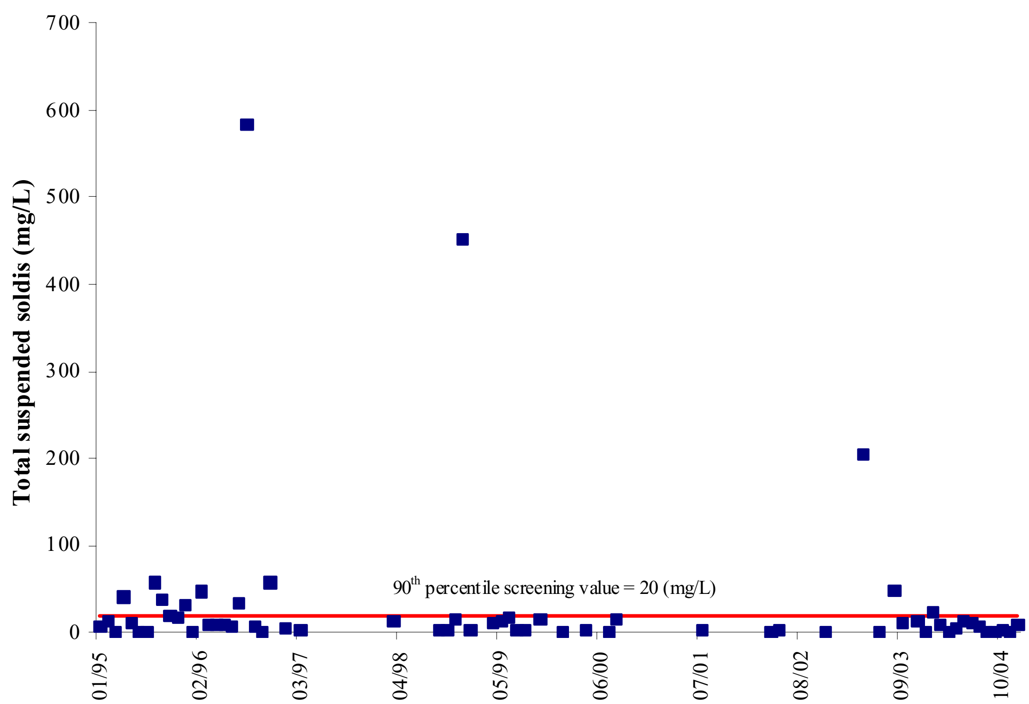

Figure 8.20 TSS concentrations at MPID 6020159.

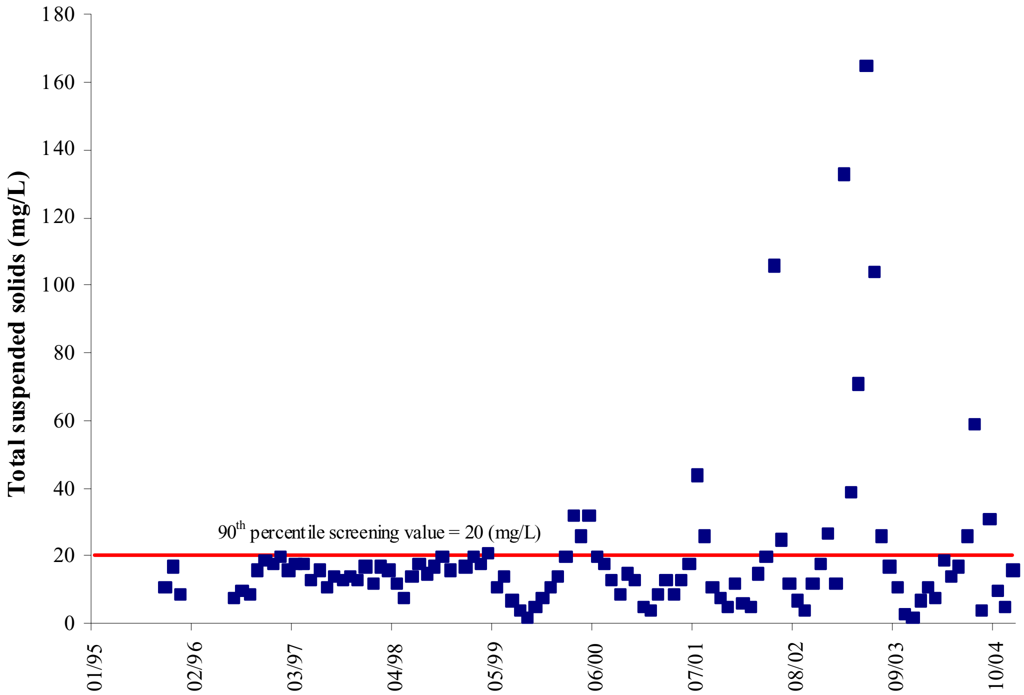

Figure 8.21 TSS concentrations at MPID 6020036.

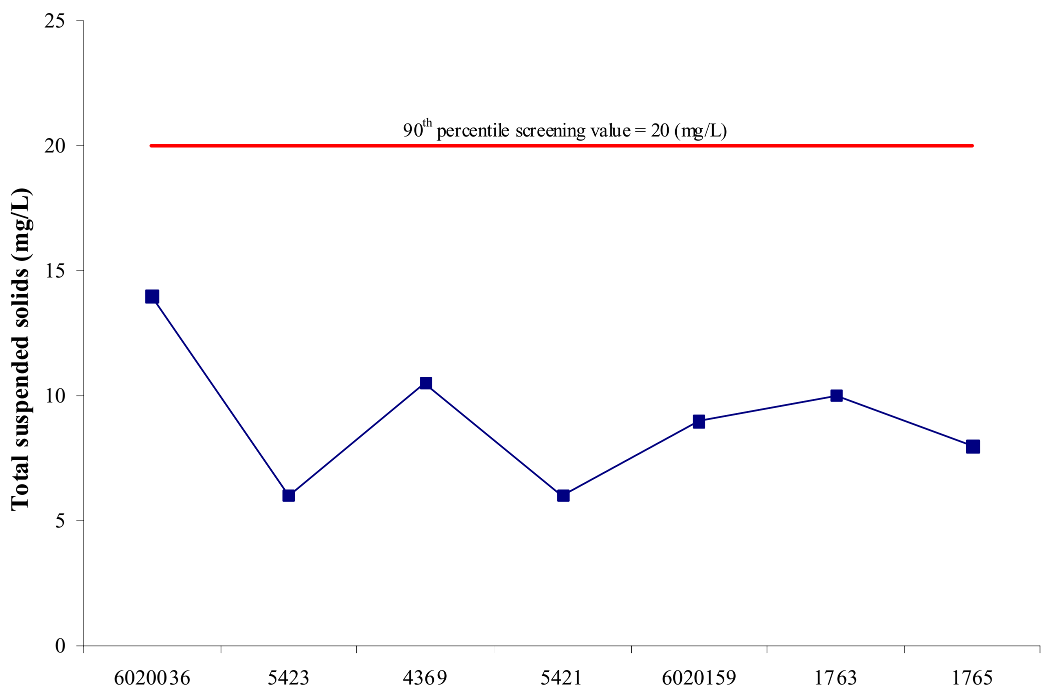

Figure 8.22 Median TSS concentrations at MPID sites on Pawpaw Creek.

8.4.2 Conductivity/Total dissolved solids (TDS)

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. TDS is a measure of the actual concentration of the dissolved ions, dissolved metals, minerals, and organic matter in water. Dissolved ions can include sulfate, calcium carbonate, chloride, etc. Therefore, even though they are two different measurements, there is a direct correlation between conductivity and TDS. In the Pawpaw Creek data set there was a Pearson Product Moment Correlation of 0.92 between conductivity and TDS.

High conductivity values have been linked to poor benthic health (Merricks, 2003) and elevated conductivity is common with land disturbance and mine drainages. A recent report on the effects of surface mining on headwater stream biotic integrity in Eastern Kentucky noted that one of the most significant stressors in these watersheds was elevated TDS (Pond, 2004). Elevated TDS concentrations impact pollution sensitive mayflies the most. Figure 8.23 from this report shows that "drastic reductions in mayflies occurred at sites with conductivities generally above 500 μmhos/cm" (Pond, 2004).

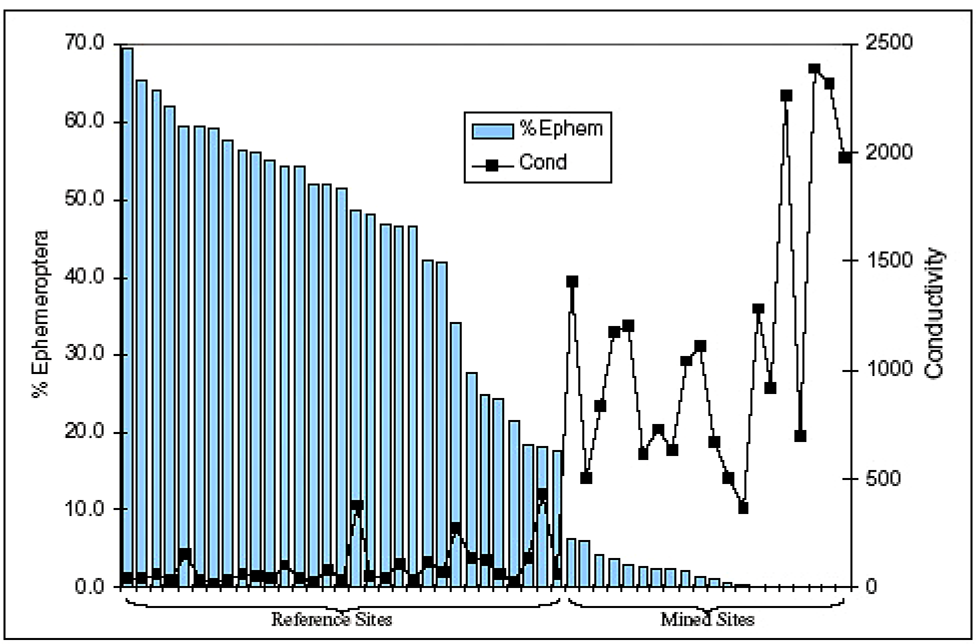

Figure 8.23 The relationship between %Ephemeroptera and conductivity from reference and mined sites (Pond, 2004).

Pond speculated that the increased salinity may irritate the gill structures on mayflies and inhibit the absorption of oxygen but research has not confirmed this. A typical reference station in this part of the state can be expected to have at least nearly 50% mayflies out of the total assemblage. The May 2005 VADEQ benthic survey on Pawpaw Creek shows that mayflies only made up 9% of the total benthic assemblage. In the development of both the Virginia and West Virginia Stream Condition Indices, the reference streams used had conductivity levels that did not exceed 500 µmhos/cm. One conductivity value was measured at VADEQ 6APPW000.49 in August 2004 and it was 484 µmhos/cm, which exceeded the 90th percentile screening value (285 µmhos/cm). Conductivity values at all seven of the DMME MPID monitoring sites exceeded the 90th percentile screening value in more than 10% of the samples collected (Figures 8.24 through 8.30). Median conductivity values are shown in Figure 8.31. Extreme values (>1,000 µmhos/cm) were measured at MPID 1765 (1,084 µmhos/cm) and 6020159 (3,070 µmhos/cm).

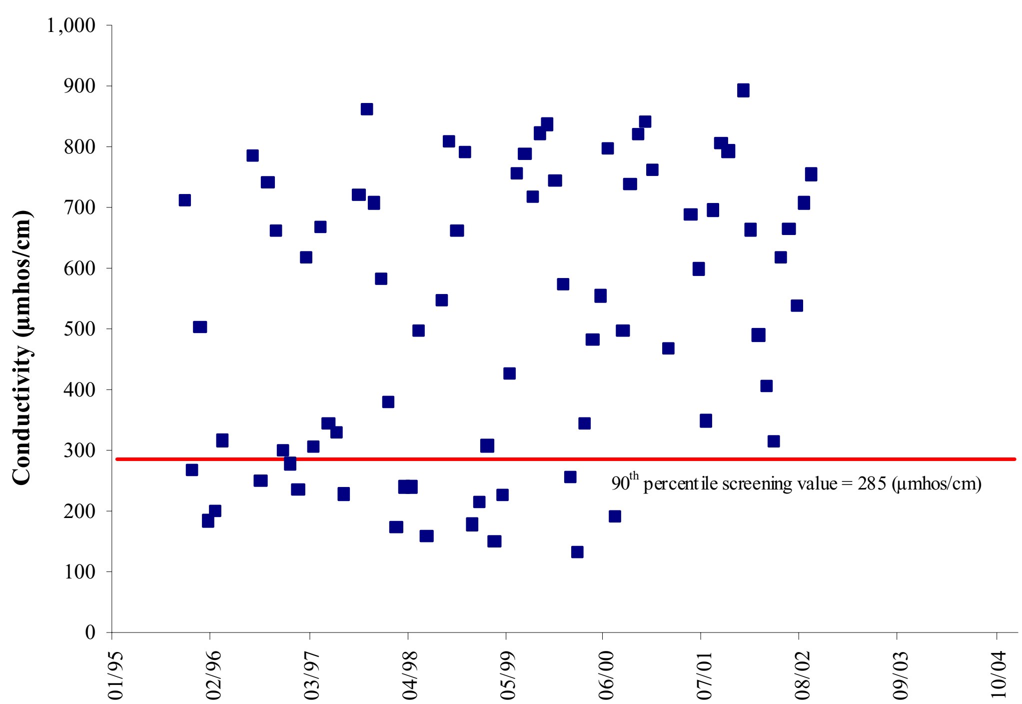

Figure 8.24 Conductivity measurements at DMME MPID 1763.

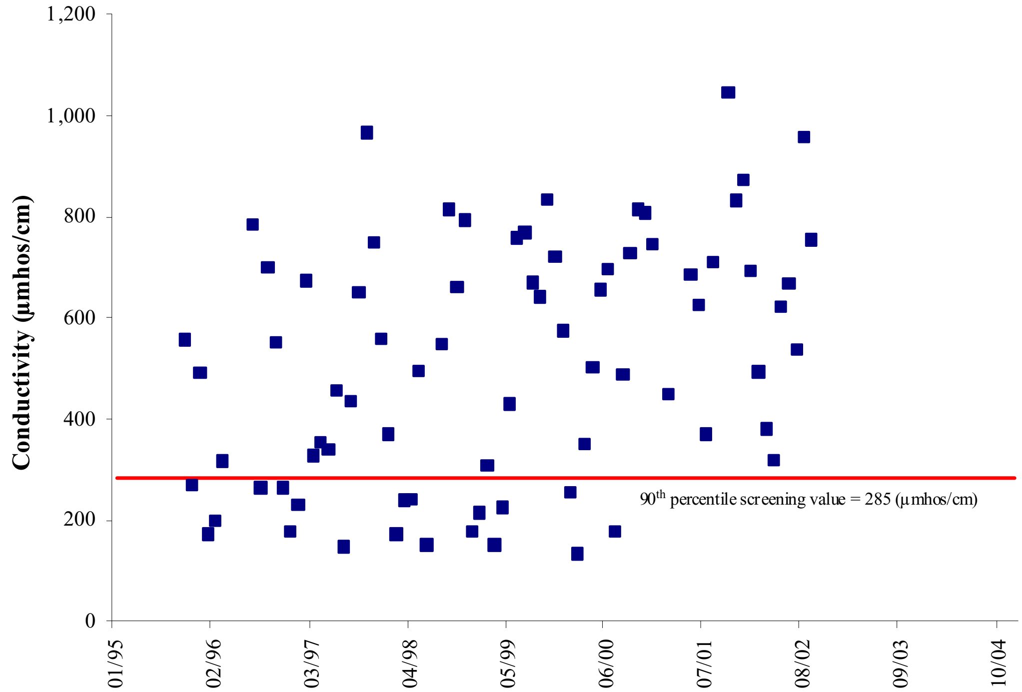

Figure 8.25 Conductivity measurements at DMME MPID 1765.

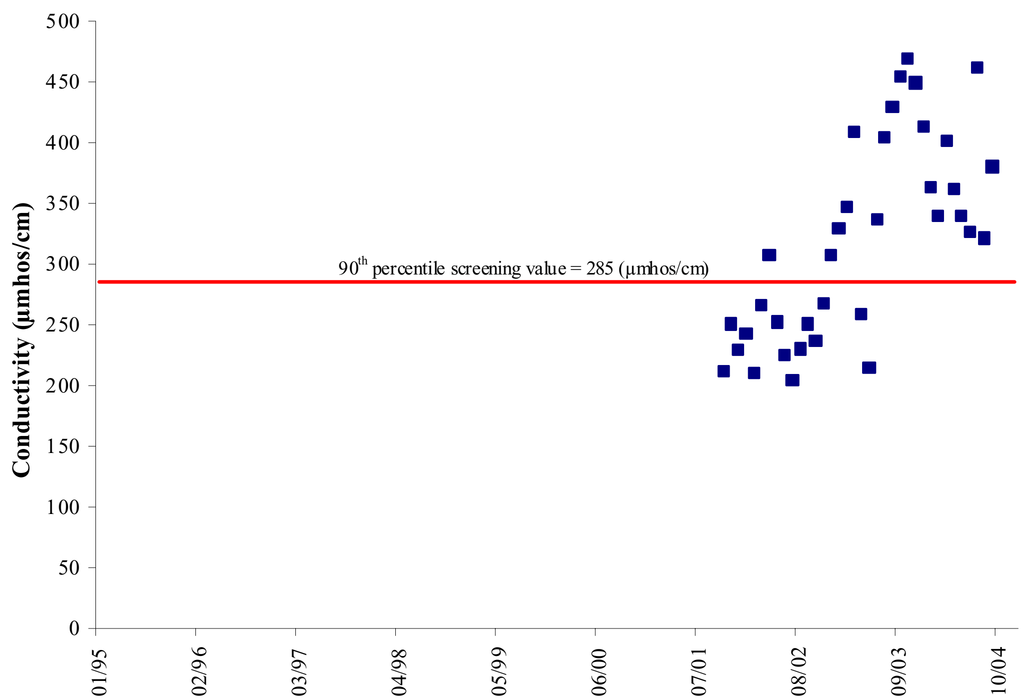

Figure 8.26 Conductivity measurements at DMME MPID 4369.

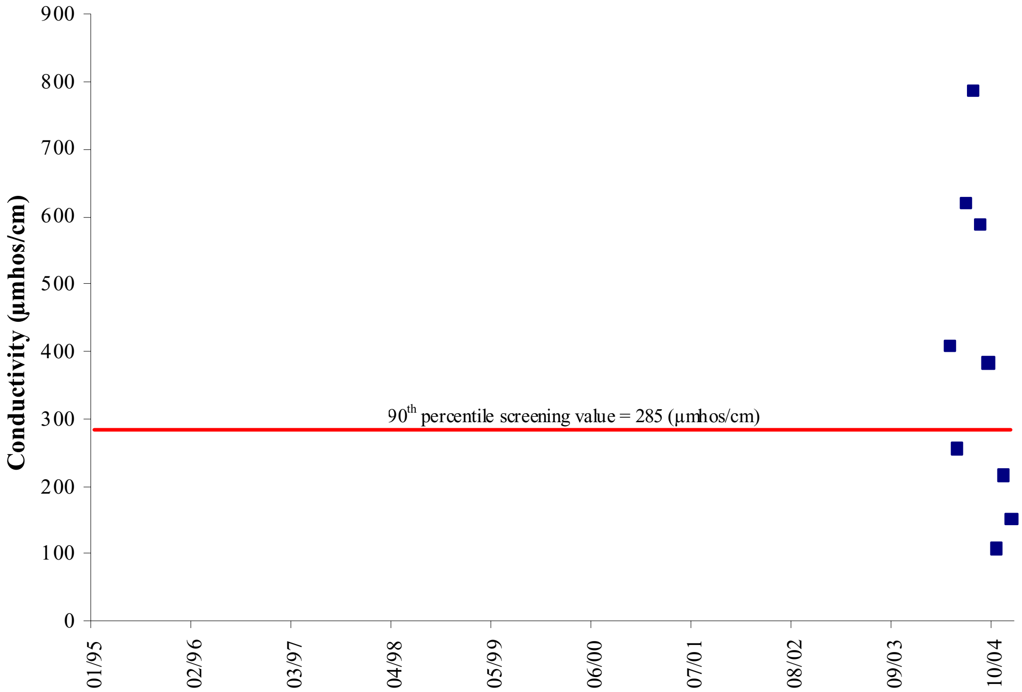

Figure 8.27 Conductivity measurements at DMME MPID 5421.

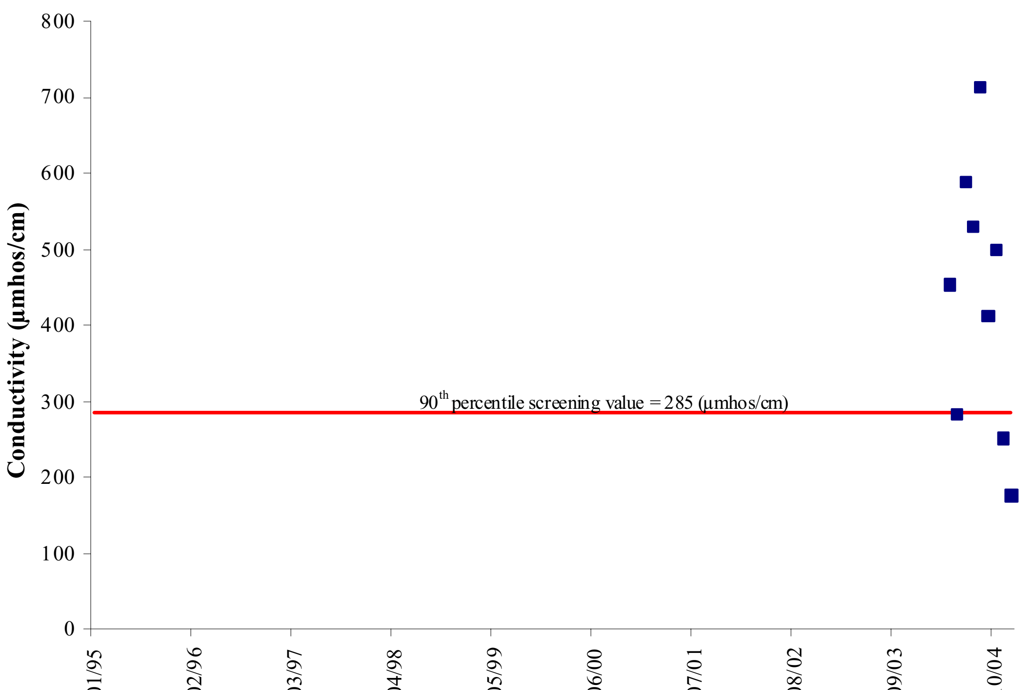

Figure 8.28 Conductivity measurements at DMME MPID 5423.

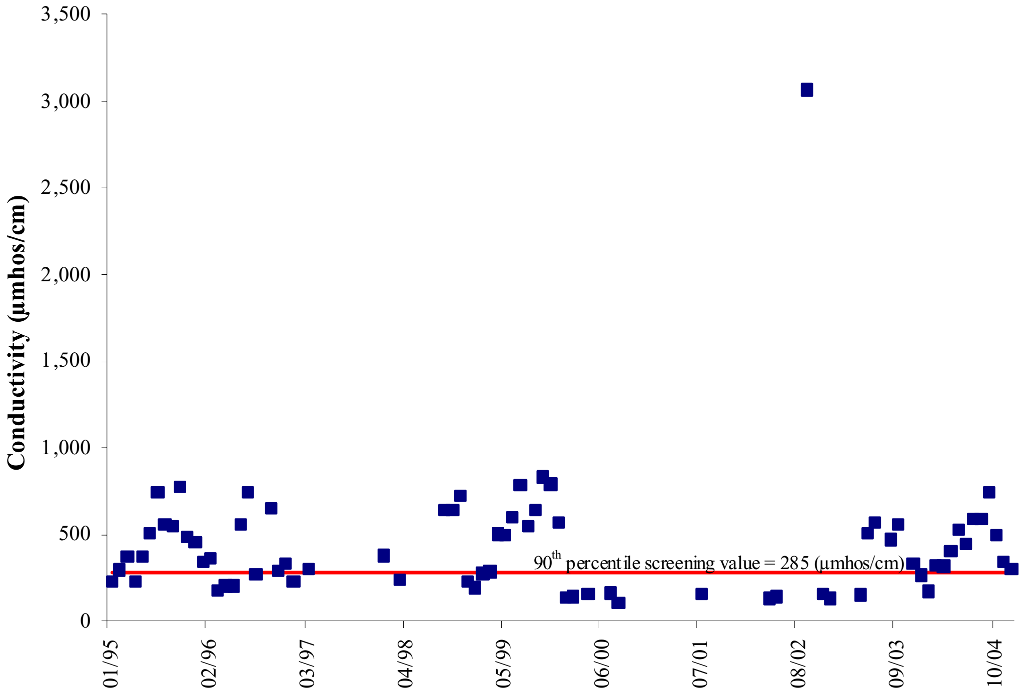

Figure 8.29 Conductivity measurements at DMME MPID 6020159.

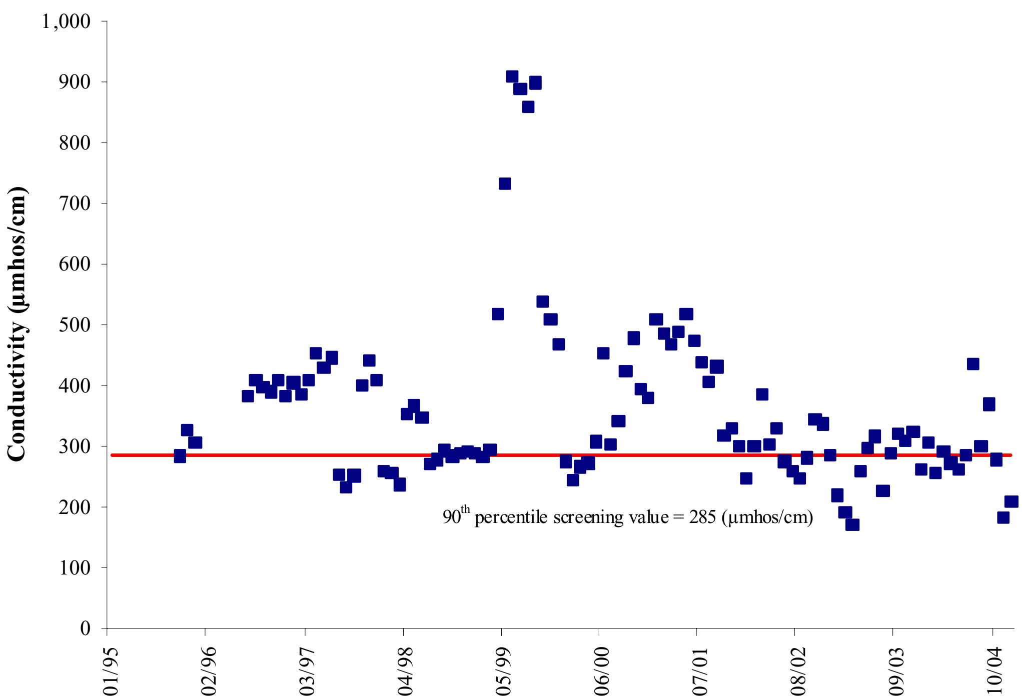

Figure 8.30 Conductivity measurements at DMME MPID 6020036.

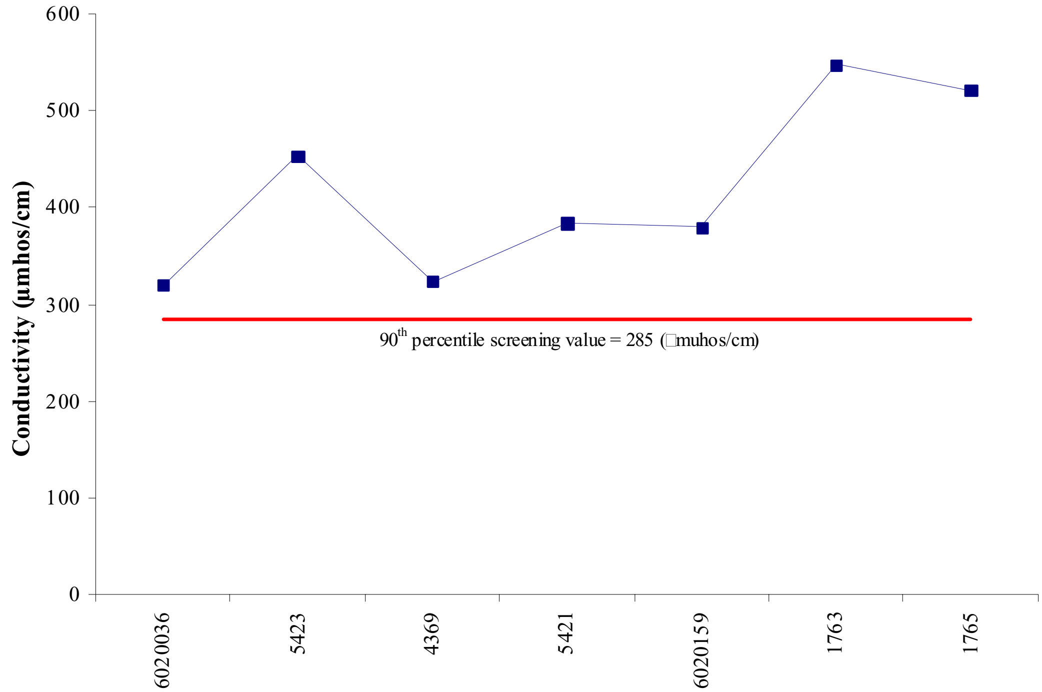

Figure 8.31 Median conductivity measurements at DMME MPID sites on Pawpaw Creek.

Pawpaw Creek exceeded the 90th percentile screening value (156 mg/L) for total dissolved solids (TDS) in more than 10% of the samples collected at all seven DMME MPID sites (Figures 8.32 through 8.38). Median TDS concentrations are shown in Figure 8.39.

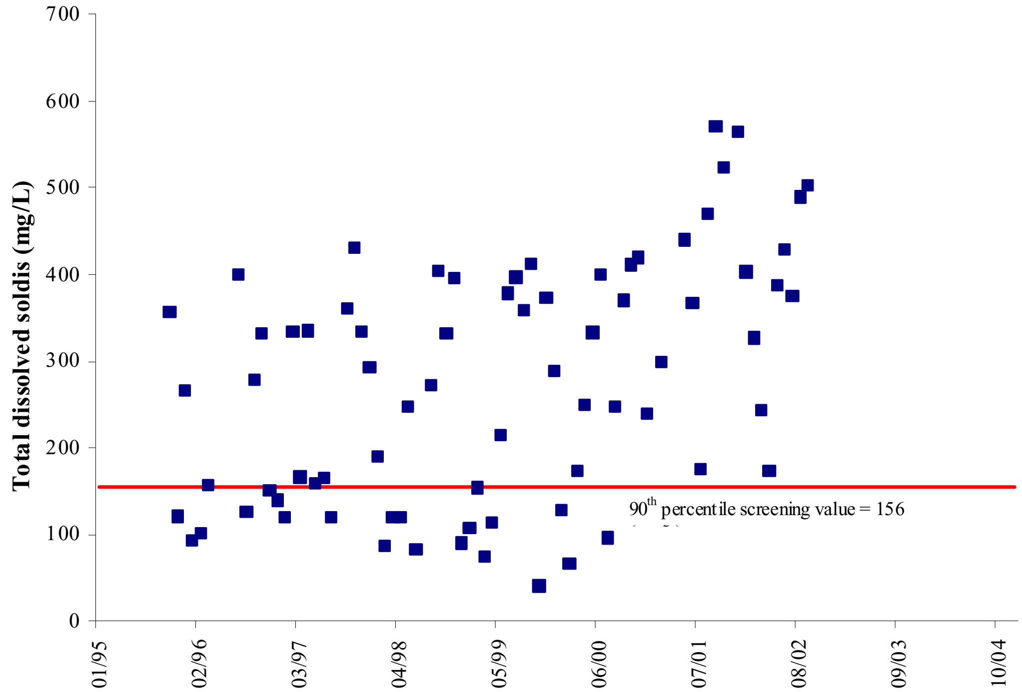

Figure 8.32 TDS concentrations at DMME station 1763.

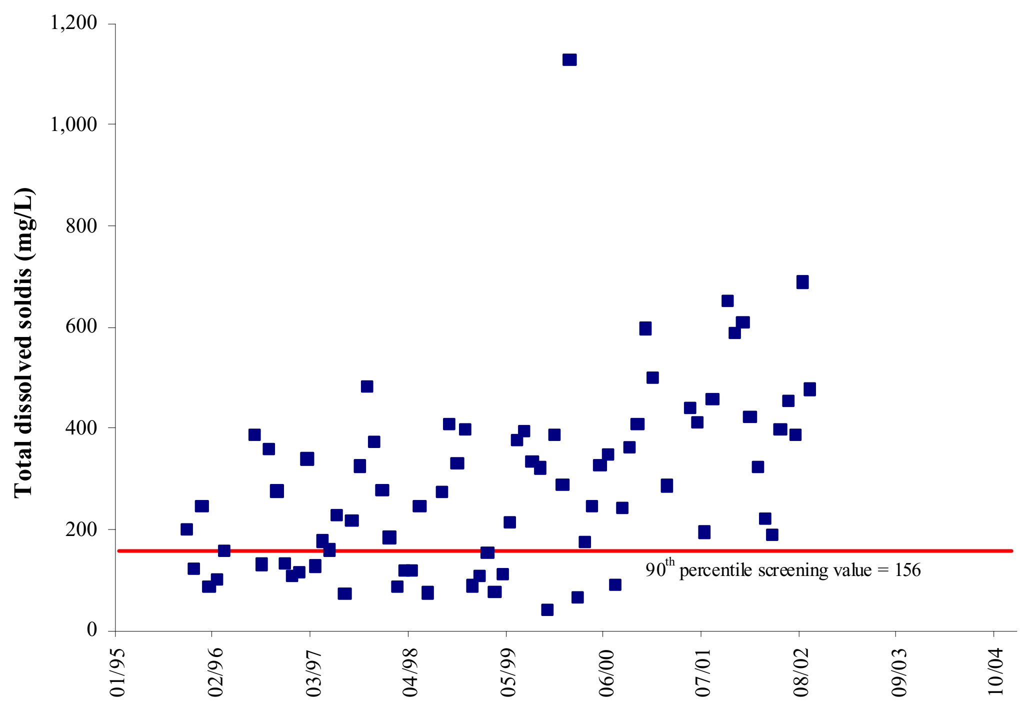

Figure 8.33 TDS concentrations at DMME MPID 1765.

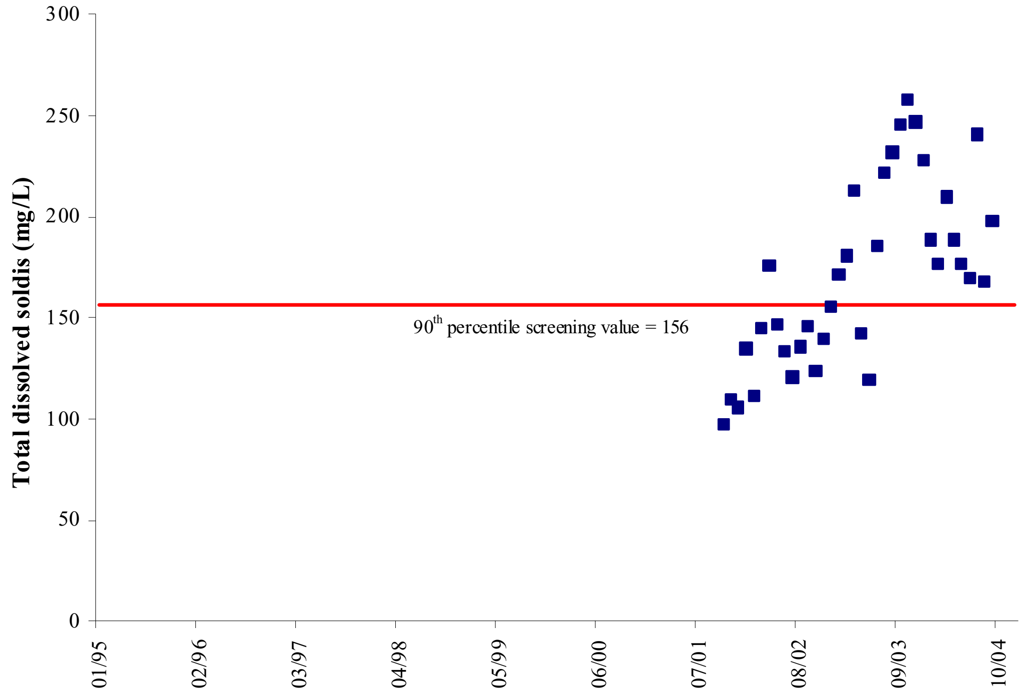

Figure 8.34 TDS concentrations at DMME MPID 4369.

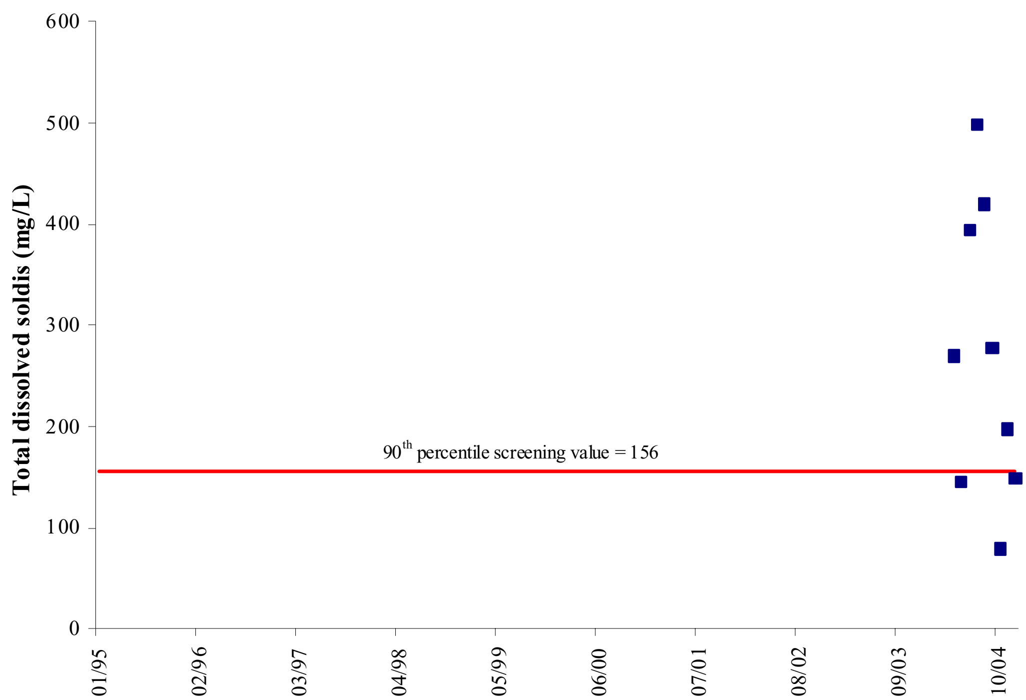

Figure 8.35 TDS concentrations at DMME MPID 5421.

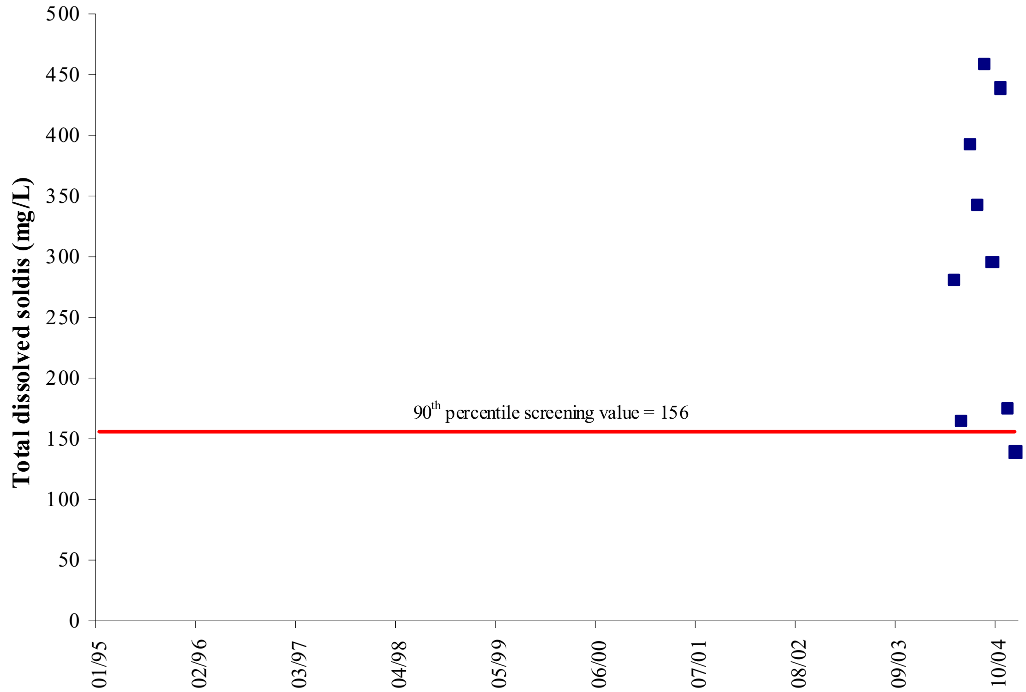

Figure 8.36 TDS concentrations at DMME MPID 5423

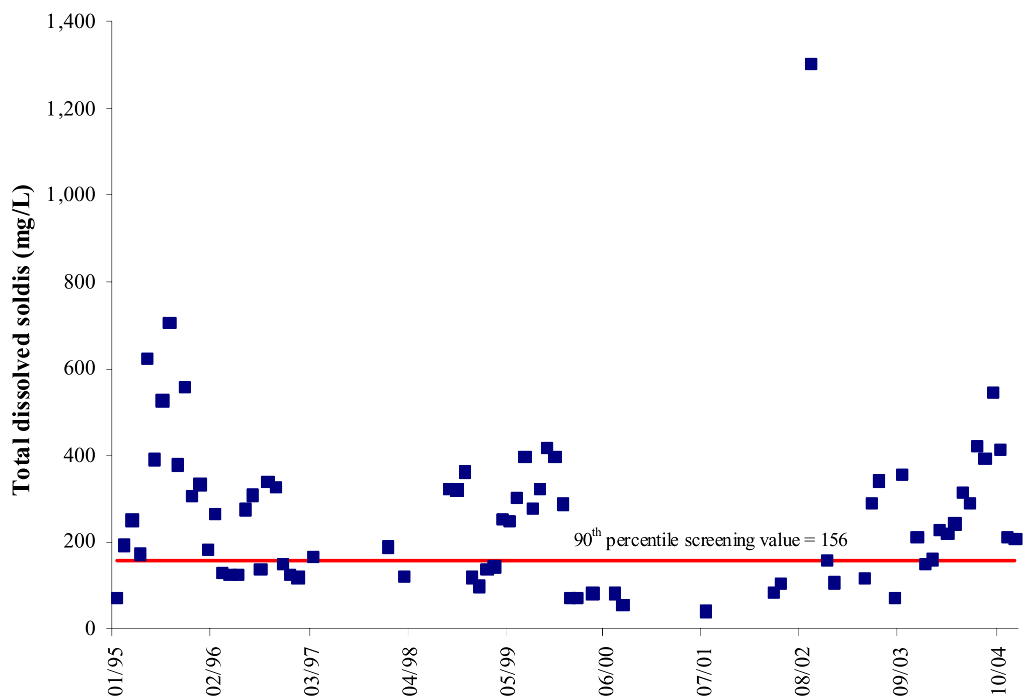

Figure 8.37 TDS concentrations at DMME MPID 6020159.

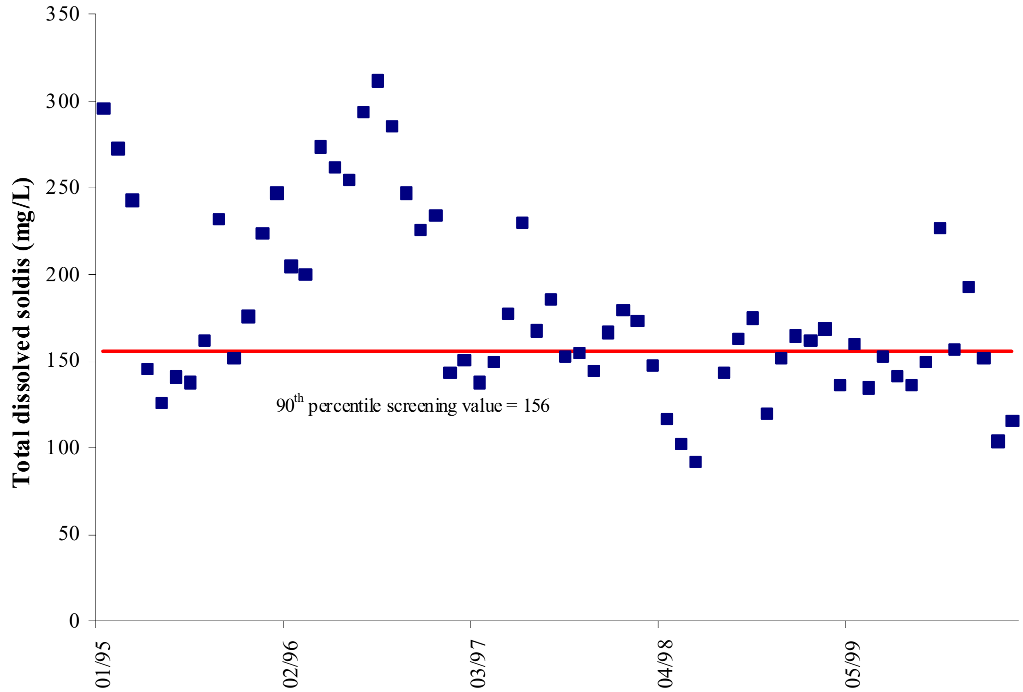

Figure 8.38 TDS concentrations at DMME MPID 6020036.

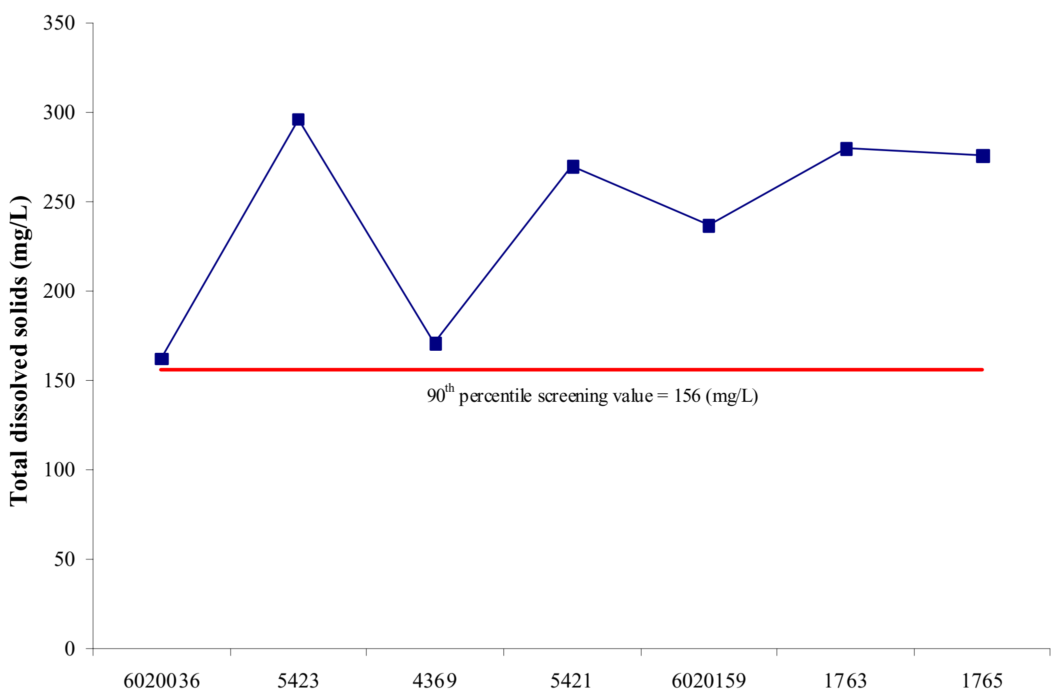

Figure 8.39 Median TDS concentrations at DMME MPIDs on Pawpaw Creek.

TDS concentrations can be harmful to aquatic organisms without causing death. Aquatic organisms balance water and internal ions through a number of different mechanisms. Therefore high concentrations and significant changes in TDS over long periods of time can place a lot of stress on the organisms. The resulting chronic stress affects processes such as growth and reproduction. Sudden large spikes in TDS concentration can be fatal. A study of TDS toxicity in a coal mining watershed in southeastern Ohio found the lowest observed effect concentration (LOEC) on the test organism *Isonychia bicolor* (a species of Mayfly) was 1,066 mg/L (Kennedy, 2002). The author carefully noted that this concentration was specific to the watershed studied, but noted that similar studies with the same test organism and TDS with varying ionic compositions were toxic between 1,018 and 1,783 mg/L (Kennedy, 2002). The study suggested that aquatic organisms should be able to tolerate TDS concentrations up to 1,000 mg/L; however, the test organism used was *Chironomous tentans*, which is considerably more pollution tolerant than *Isonychia bicolor* (Kennedy, 2002). Research also indicates that the likely mechanism(s) of TDS benthic macroinvertebrate mortality is from gill and internal tissue dehydration, salt accumulation and compromised osmoregulatory function. In fact, the rate of change in TDS concentrations may be more toxic to benthic macroinvertebrates than the TDS alone (Kennedy, 2002).

It is clear from the data available that conductivity and TDS values are too high and there have been very large fluctuations over the sampling period. There is little doubt that the extremely high TDS concentrations often present in Pawpaw Creek are responsible for depressing the sensitive benthic community. Therefore, conductivity and TDS are considered probable stressors. Modeling and subsequent allocations will focus on TDS.

8.5 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on the possible and probable stressors. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

The results of the Seasonal Kendall Test used to detect long-term trends are shown in Tables 8.5 through 8.9.

Table 8.5 Trend Analysis results for MPID 1763.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	34.000
Total Dissolved Solids, mg/L	28.450
Total Suspended Solids, mg/L	-2.000

Table 8.6 Trend Analysis results for MPID 1765.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	45.750
Total Dissolved Solids, mg/L	42.500
Total Suspended Solids, mg/L	-1.667

Table 8.7 Trend Analysis results for MPID 4369.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	68.000
Total Dissolved Solids, mg/L	34.000
Total Suspended Solids, mg/L	No Trend

Table 8.8 Trend Analysis results for MPID 6020036.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	-12.667
Total Dissolved Solids, mg/L	-18.000
Total Suspended Solids, mg/L	No Trend

Table 8.9 Trend Analysis results for MPID 6020159.

Water Quality Constituent	Trend
Conductivity, 25°C Micromho	No Trend
Total Dissolved Solids, mg/L	No Trend
Total Suspended Solids, mg/L	No Trend
Manganese, μg/L	--

"--": insufficient data

Table 8.10 Summary of Mood's Median Test on Conductivity at MPID 1763.

Season	Mean	Min	Max	Median Group	
Winter	322.00	135.00	665.00	A	
Spring	493.88	162.00	162.00	A	B
Summer	616.74	193.00	824.00		B
Fall	640.05	180.00	894.00		B

Table 8.11 Summary of Mood's Median Test on Conductivity at MPID 1765.

Season	Mean	Min	Max	Median Group	
Winter	323.84	134.00	693.00	A	
Spring	485.00	152.00	759.00	A	B
Summer	588.00	149.00	958.00		B
Fall	642.33	178.00	1048.00		B

Table 8.12 Summary of Mood's Median Test on Conductivity at MPID 6020159.

Season	Mean	Min	Max	Median Group	
Winter	269.86	142.00	382.00	A	
Spring	377.39	137.00	605.00	A	
Summer	666.94	113.00	3070.00		B
Fall	467.32	135.00	835.00	A	B

Table 8.13 Summary of Mood's Median Test on TDS at MPID 1763.

Season	Mean	Min	Max	Median Group	
Winter	177.00	68.00	404.00	A	
Spring	271.18	83.00	441.00	A	B
Summer	339.05	97.00	572.00		B
Fall	305.83	42.00	566.00		B

Table 8.14 Summary of Mood's Median Test on TDS at MPID 1765.

Season	Mean	Min	Max	Median Group	
Winter	226.42	67.00	1129.00	A	
Spring	267.29	76.00	456.00	A	B
Summer	323.89	75.00	690.00		B
Fall	339.60	42.00	654.00		B

Table 8.15 Summary of Mood's Median Test on TDS at MPID 6020159.

Season	Mean	Min	Max	Median Group	
Winter	157.83	72.00	266.00	A	
Spring	244.72	83.00	624.00	A	B
Summer	368.95	42.00	1304.00		B
Fall	272.68	108.00	558.00	A	B

9. REFERENCE WATERSHED SELECTION

A reference watershed approach was used to estimate the necessary load reductions that are needed to restore a healthy aquatic community and allow the streams in the Knox Creek watershed to achieve their designated uses. This approach is based on selecting a non-impaired watershed that has similar land use, soils, stream characteristics (*e.g.*, stream order, corridor, slope), area (not to exceed double or be less than half that of the impaired watershed), and is in the same ecoregion as the impaired watershed. The modeling process uses load rates or pollutant concentrations in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current load rates and establish what reductions are necessary to meet the load rates of the non-impaired watershed.

9.1 Reference Watershed Selection - Knox Creek

Eleven potential reference watersheds were selected from the Central Appalachians ecoregion for analyses that would lead to the selection of a reference watershed for Knox Creek (Figure 9.1). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, land use, soils, slope, stream order, watershed size). Tables 9.1 and 9.2 show Knox Creek and the potential reference streams and information used to compare them.

Based on these comparisons and after conferring with state and regional VADEQ personnel, the Dismal Creek watershed was selected as the reference watershed for the Knox Creek watershed. The Dismal Creek watershed is a good choice as the reference watershed due to the similarities in size, soil characteristics, and land use. Information that is needed to select numeric endpoints is readily available from water quality monitoring performed by DMME and VADEQ. The Dismal Creek watershed has a history of mining activity.

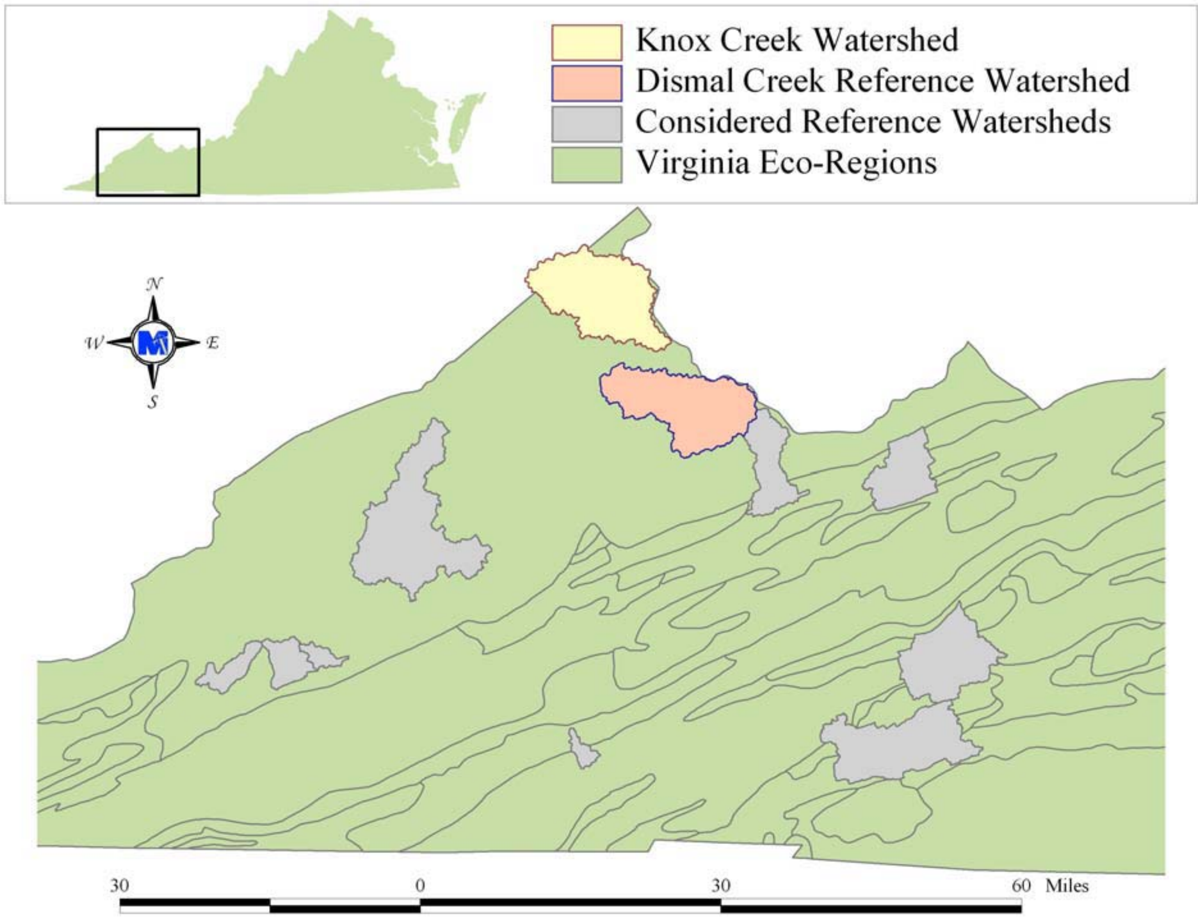

Figure 9.1 Location of selected and potential reference watersheds.

Table 9.1 Reference watershed selection for Knox Creek – Part1.

Stream	Knox Creek	Dismal Creek	McClure River	Middle Fork Holston River	Indian Creek	South Fork Powell River	Clinch River
Basin	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS
HUC	05070201	05070202	05070202	06010102	06010206	06010206	06010206
Area (acres)	56,209	54,533	68,039	37,809	21,384	8,420	22,943
Stream Order	3	4	4	3	3	3	3
Land use:							
Active Mining	1,158	129.21	465.68	11.56	4.67		0
AML	2,123	8.01	0	591			316
Barren		833.52	700.75089	91.85	162.57		34.25
Commercial		8.01	100.30	591.34	0.89	2.00	316.24
Crops	432	60.94	380.95	390.52	406.53	0.22	614.24
Forest	50,939	53,025	64,369	27,388	19,081	8,015	11,729
Pasture	155.59	353.38	1,691	8695.00	1,649	305.79	9,594
Reclaimed							
Residential	54.22	86.95	89.40	600.68	54.04	1.33	596.01
Water	625.45	30.47	228.84	8.01	13.79	66.05	38.25
Wetlands		5.34	11.79	32.69	14.01	32.91	22.91
Slope (degrees):	25.66	24.12	22.87	14.78	17.08	16.49	14.28
Aspect (degrees)	185.30	188.88	181.76	192.69	183.60	188.89	201.25
Soil Type:							
KY801	6.3						
TN134				26.05			3.86
TN151				29.96	24.07	4.44	63.44
TN164					0.648		
VA001			10.62	10.92			1.86
VA004		13.07		22.75			
VA005				10.33			
VA006							
VA016	5.01						27.26
VA054					5.98		3.59
VA055					65.39		

Table 9.1 Reference watershed selection for Knox Creek – Part1 (cont.).

Stream	Knox Creek	Dismal Creek	McClure River	Middle Fork Holston River	Indian Creek	South Fork Powell River	Clinch River
VA056		86.93	89.38		3.91	95.56	
VA057	4.94						
VA078	83.75						
Soil Characteristics:							
Hydrologic Group (avg):	2.7	2.55	2.69	2.7	2.53	2.68	2.35
Erodibility Kffactor	0.22	0.24	0.22	0.23	0.27	0.22	0.25
Available Water Capacity	0.12	0.1	0.09	0.10	0.11	0.09	0.11
Unsat SMC	0.80	0.97	0.74	1.17	1.03	0.78	1.31
EcoRedgion:							
Cumberland Mountains	100	100	100		68.22	100	3.39
Southern Dissected Ridges and Knobs				23.51			
Southern Igneous Ridges and Mountains				30.25	31.78		70.36
Southern Limestone/Dolomite Valleys and Low Rolling Hills				6.36			26.25
Southern Sandstone Ridges				19.7			
Southern Sedimentary Ridges				20.17			

Table 9.2 Reference watershed selection for Knox Creek – Part2.

Stream	Knox Creek	Stony Creek	Indian Creek	Little Stony Creek	Greendale Creek	South Fork Holston River
Basin	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS	Tnn_BS
HUC	05070201	06010205	06010206	06010205	06010101	06010102
Area (acres)	56,209	10,360	18,288	4,094	3,442	48,162
Stream Order	3	4	3	3	4	3
Land use:						
Active Mining	1,158	0	4.67		0.22	0.222
AML	2,123	0				163.23
Barren		3.336	162.12	1.112		24.02
Commercial		0	0.896	0.22	3.11	163.23
Crops	432	2.002	223.28		20.24	247.52
Forest	50,939	10,337	16,648	4,04	2622.20	40,237
Pasture	155.59	3.78	1,204	1.78	776.14	6,804
Reclaimed						
Residential	54.22	0	18.90		20.90	663.84
Water	625.45	0.445	10.45	30.91		4.89
Wetlands		17.346	13.79	20.46	1.78	20.24
Slope (degrees):	25.66	18.24	16.93	14.68	16.06	15.66
Aspect (degrees)	185.30	178.37	182.17	170.44	186.32	196.79
Soil Type:						
KY801	6.3					
TN134					23.13	32.74
TN151			16.92		56.49	11.87
TN164					0.974	6.97
VA001						6.57
VA004						24.29
VA005						4.32
VA006						13.25
VA016	5.01				19.41	
VA054			7.01			
VA055			71.47			

Table 9.2 Reference watershed selection for Knox Creek – Part2 (cont.).

Stream	Knox Creek	Stony Creek	Indian Creek	Little Stony Creek	Greendale Creek	South Fork Holston River
Soil Type:						
VA056		100	4.59	100		
VA057	4.94					
VA078	83.75					
Soil Characteristics:						
Hydrologic Group (avg):	2.7	2.7	2.57	2.7	2.34	2.46
Erodibility Kffactor	0.22	0.22	0.267	0.218	0.253	0.233
Available Water Capacity	0.12	0.09	0.088	0.09	0.12	0.106
Unsat SMC	0.80	0.75	0.99	0.746	1.35	1.22
EcoRegion:						
Cumberland Mountains	100.00	100	78.37	100		
Southern Dissected Ridges and Knobs						
Southern Igneous Ridges and Mountains			21.63		65.56	20.63
Southern Limestone/Dolomite Valleys and Low Rolling Hills						
Southern Sandstone Ridges						71.83
Southern Sedimentary Ridges					34.44	7.51

9.2 Reference Watershed Selection - Pawpaw Creek

Nine potential reference watersheds were selected from the Central Appalachians ecoregion for analyses that would lead to the selection of a reference watershed for Pawpaw Creek (Figure 9.2). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, land use, soils, slope, stream order, watershed size). Tables 9.3 and 9.4 show Pawpaw Creek and the potential reference streams and information used to compare them. Based on these comparisons and after conferring with state and regional VADEQ personnel, the Middle Creek watershed was selected as the reference watershed for the Pawpaw Creek watershed.

The Middle Creek watershed is a good choice for the reference watershed because of the similarities in land use, stream order and soil characteristics. Information that is needed to select numeric endpoints is readily available from water quality monitoring performed by DMME and VADEQ. The Middle Creek watershed has a history of mining activity and has recovered from a benthic impairment. In addition, the necessary reductions in loadings to the impaired streams can be shown as achievable targets, as exemplified by the improvement in water quality of Middle Creek. Computer simulation models have been developed to simulate flow, total dissolved solids and sediment loads in the Middle Creek watershed.

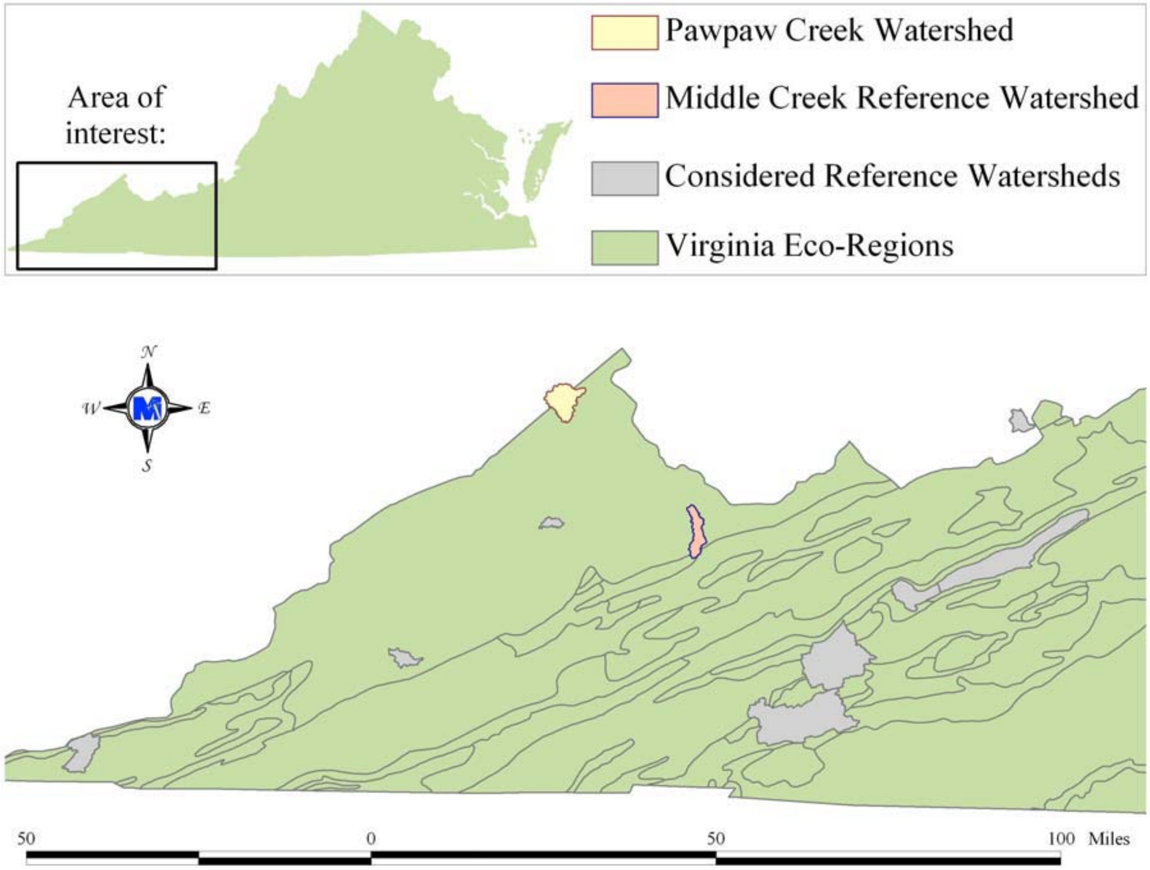

Figure 9.2 Location of selected and potential reference watersheds.

Table 9.3 Reference watershed selection for Pawpaw Creek – Part1.

Stream	Pawpaw Creek	Middle Creek	South Fork Powell River	Stony Fork	Fox Creek	Little Stony Creek	Martin Creek
Basin	Tnn_BS	Tnn_BS	Tnn_BS	New River	Tnn_BS	Tnn_BS	Tnn_BS
HUC	05070201	06010205	06010206	05050001	05070202	06010205	06010206
Area (acres)	11,729	7,148	8,420	10,625	2,196	4,094	11,220
Stream Order	2	2	3	2	2	3	2
Land use:							
Active Mining	135						
AML	510.59	77.84					
Barren		0.89	2.00	21.79	42.03	1.11	1.56
Commercial		17.79		13.12		0.22	0.44
Crops	16	31.36	0.22	30.69	7.34	0.00	501.93
Forest	10,798	6,932	8,015	10,437	2,129	4,036	6,357
Pasture	24.23	57.60					
Reclaimed	88.65		305.79	119.20	15.34	1.78	4,329
Residential	3.17	26.24					
Salted Roads	31.60		1.33	4.45	0.22	0.00	20.46
Water	101.85	1.78	66.05	1.56	1.33	30.91	6.23
Wetlands		0.22	32.91	0.22		20.46	5.11
Slope (degrees):	26.90	21.15	16.49	18.78	25.27	14.68	13.49
Aspect (degrees)	178.49	186.4	188.89	182.88	193.42	170.44	186.64
Soil Type:							
KY801	25.72						
TN134				72.94			
TN151			4.44	18.46			64.66
TN164		1.47					
VA001				8.6			
VA002							
VA003							
VA004							13.46
VA005							
VA006							

Table 9.3 Reference watershed selection for Pawpaw Creek – Part1 (cont.).

Stream	Pawpaw Creek	Middle Creek	South Fork Powell River	Stony Fork	Fox Creek	Little Stony Creek	Martin Creek
Soil Type:							
VA007							
VA016	4.13						
VA017							4.78
VA018							
VA020							
VA054							
VA055		76.95					
VA056		21.58	95.56		100	100	17.11
VA057	11.84						
VA062							
VA077							
VA078	58.31						
Soil Characteristics:							
Hydrologic Group (avg):	2.74	2.64	2.68	2.7	2.7	2.7	2.3
Erodibility Kffactor	0.22	0.26	0.22	0.22	0.22	0.22	0.25
Available Water Capacity	0.09	0.097	0.09	0.08	0.09	0.09	0.13
Unsat SMC	0.86	0.86	0.78	1.03	0.75	0.75	1.29
EcoRegion:							
Cumberland Mountains	100	92.27	100		100	100	5.2
Greenbrier Karst	0						
Interior Plateau	0						
Southern Dissected Ridges and Knobs	0			52.55			
Southern Igneous Ridges and Mountains	0	1.93					76.27
Southern Limestone/Dolomite Valleys and Low Rolling Hills	0			47.45			18.54
Southern Sedimentary Ridges	0	5.8					
Southern Sandstone Ridges	0						

Table 9.4 Reference watershed selection for Pawpaw Creek – Part2.

Stream	Pawpaw Creek	Adair Run	Little Walker Creek	Middle Fork Holston River
Basin	Tnn_BS	New River	New River	Tnn_BS
HUC	05070201	05050002	05050002	06010102
Area (acres)	11,729	4,399	36,096	37,809
Stream Order	2	2	2	3
Land use:				
Active Mining	135			11.56
AML	510.59			
Barren		1.56	128.32	91.85
Commercial		0.00	35.5824	591.34
Crops	16	127.43	539.96	390.52
Forest	10,798	3,718	32,665	27,388
Pasture	24.23			
Reclaimed	88.65	548.41	2,713	8,668
Residential	3.17			
Salted Roads	31.60	0.67	2.45	600.68
Water	101.85	2.00	4.67	8.01
Wetlands		0.00		32.69
Slope (degrees):	26.90	15.94	18.55	14.78
Aspect (degrees)	178.49	158.98	177.41	192.69
Soil Type:				
KY801	25.72			
TN134			71.28	26.05
TN151				29.96
TN164			13.22	
VA001			15.5	10.92
VA002				
VA003				
VA004				22.75
VA005				10.33
VA006				

Table 9.4 Reference watershed selection for Pawpaw Creek – Part2 (cont.).

Stream	Pawpaw Creek	Adair Run	Little Walker Creek	Middle Fork Holston River
Soil Type:				
VA007				
VA016	4.13			
VA017				
VA018				
VA020				
VA054		0.31		
VA055				
VA056				
VA057	11.84	2.91		
VA062		96.78		
VA077				
VA078	58.31			
Soil Characteristics:				
Hydrologic Group (avg):	2.74	2.77	2.75	2.7
Erodibility Kffactor	0.22	0.25	0.23	0.23
Available Water Capacity	0.09	0.10	0.08	0.09
Unsat SMC	0.86	1.14	0.98	1.17
EcoRegion:				
Cumberland Mountains	100			
Greenbrier Karst		100		
Interior Plateau				
Southern Dissected Ridges and Knobs				23.51
Southern Igneous Ridges and Mountains				30.25
Southern Limestone/Dolomite Valleys and Low Rolling Hills			100	6.36
Southern Sedimentary Ridges				20.17
Southern Sandstone Ridges				71.83

10. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT – TDS AND SEDIMENT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of benthic TMDLs for the Knox Creek and Pawpaw Creek watersheds, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application for TDS (Knox and Pawpaw Creeks) and sediment (Pawpaw Creek) are discussed.

As described in Chapter 9 of this document, Dismal Creek in Buchanan County, VA was selected as the reference watershed for Knox Creek. The 90th percentile TDS concentration from Dismal Creek (369 mg/L) was used to define the benthic TMDL load for the Knox Creek watershed.

Also described in Chapter 9 is the selection of Middle Creek in Tazewell County, VA as the reference watershed for Pawpaw Creek. Using a reference watershed with a history of coal mining ensures that the TDS and sediment TMDLs developed for Pawpaw Creek are achievable scenarios. The 90th percentile TDS concentration (from 10 samples) from Middle Creek (334 mg/L) and the average annual sediment load from the Middle Creek watershed were used to define the benthic TMDL loads for the Pawpaw Creek watershed.

10.1 Total Dissolved Solids – HSPF model

10.1.1 Modeling Framework Selection - HSPF

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate TDS existing conditions and to perform the TDS TMDL allocations for both Knox Creek and Pawpaw Creek. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed. The hydrology model is explained in Chapter 4.

10.1.2 HSPF Model Setup - TDS

Two deep mine discharges were present in the Knox Creek watershed during the hydrology calibration time period (Figure 10.1). TDS loads were incorporated into the HSPF model calibrated for hydrology for Knox Creek. Deep mine discharges were modeled as external time series with flow and TDS inputs to a RCHRES. TDS was modeled as a conservative constituent, meaning there is no “die-off” factor. The pathways for delivery to the stream are transport with surface runoff, direct deposition from point sources, interflow, and groundwater. Sensitivity analyses were performed on the TDS models to ascertain how the model responds to changes in each parameter.

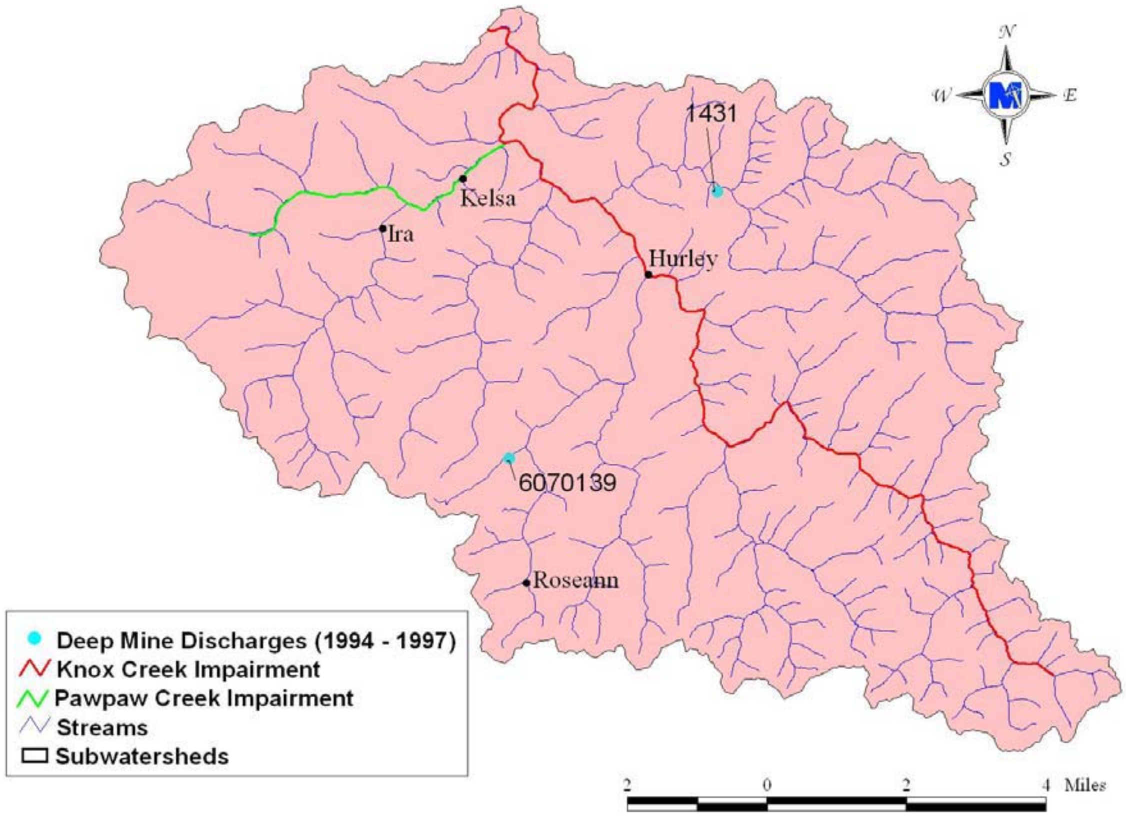

Figure 10.1 Point sources from deep mines in the Knox Creek and Pawpaw Creek watersheds, operational during the calibration period.

10.1.3 TDS Source Representation

Both point and nonpoint sources can be represented in the model. For Knox Creek and Pawpaw Creek, permitted point sources during the modeled period included water pumped from deep mines. Discharges that were not driven by precipitation (*i.e.,* deep-mine discharges) were modeled based on the monitored values by adding a time series of pollutant and flow inputs to the stream. Nonpoint sources were modeled as having three potential delivery pathways, delivery with surface runoff, delivery through interflow, and delivery through groundwater. Pollutants associated with interflow and/or groundwater were modeled by assigning a constant concentration for each in a particular PERLND. Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* existence of control structures). Data representing the water quality calibration period were used to develop the model used in this study.

10.1.3.1 TDS Point Sources and Permitted Sources

Two deep mine discharges in the Knox Creek watershed were operational during the water quality calibration period (Figure 10.1). There are currently two VPDES permitted for fecal control, two carwash permits, and two general permits for residential sewage treatment discharge. These point sources, which have flows that are not directly driven by rainfall events, were modeled as flowing directly into the stream network. They were modeled as external time series with flow and TDS inputs to a RCHRES.

The direct mine discharges were modeled with their monitored flow and TDS concentrations. The carwash permits were modeled as only discharging water (no TDS). The residential discharge operating under a general permit in the Knox Creek watershed was modeled with the design flow of 0.001 MGD (million gallons per day) and with 250 mg/L of TDS (Metcalf and Eddy, 1991).

The TDS load from uncontrolled discharges (straight pipes) was calculated by multiplying the flow of sewage per person per day by the number of people estimated to be in homes with straight pipes (Chapter 3) times a TDS concentration of 500 mg/L (Metcalf and Eddy, 1991). This load was modeled as flowing directly to the stream network.

Runoff from- surface mine areas is collected in ponds. These ponds are considered permitted discharges since the mining industry and DMME are required to monitor the outflow. As discussed in Chapter 4, a runoff event is necessary to transport TDS from the land to the pond water. The mining ponds were assumed not to reduce the TDS load from the collected water and all TDS in runoff from mining land uses was routed to the stream via the ponds.

10.1.3.2 TDS Nonpoint Sources

Nonpoint source contributions from the ten land use categories (Table 4.1) were assumed to be delivered to the stream flow system in surface runoff, interflow and groundwater. The HSPF model was used to link pollutants from nonpoint sources with downstream water quality.

10.1.3.3 Road Salt Applications

Annual road salt application rates for Buchanan County were provided by the Virginia Department of Transportation (VDOT). The road salt applications were deposited on paved roads in the watershed via the model on days with recorded snowfall. The daily rate was calculated using a ratio of snowfall on a given day to the total snowfall during the modeling time period. This was done to simulate the practice of applying less salt for light snowfall and more salt during heavy snow events. These daily salt applications were used to estimate TDS in surface runoff from paved roads during the winter months. The road salt applications were modeled using an external time series depositing on the paved road PERLNDs in the watershed.

10.1.3.4 Road Brine Applications

VDOT does not apply brine to unpaved roads to control dust in Buchanan County. Brine was not modeled in this study.

10.1.4 Selection of Representative Modeling Period - HSPF

Selection of the modeling periods was based on three factors: availability of data (discharge and water quality), the degree of land-disturbing activity, and the need to represent critical hydrologic conditions. As described in Chapter 4, the primary limiting factor in determining the modeling period for the Knox Creek watershed was the selection of a timeframe with relatively stable land use and man-made hydraulics (ponds). The hydrology calibration period was determined as 10/1/1994 to 9/30/1997. In the case of Knox Creek and Pawpaw Creek, TDS data were typically sampled on a monthly basis. Total dissolved solids data were available at various locations throughout the watershed. Since there was a limited amount of data for both impairments during the identified period of relative stability, it was determined that the modeling effort would be more successful if all of these data were used for calibration, rather than dividing the dataset into smaller datasets for calibration and validation. The TDS calibration period was 10/1/1993 to 9/30/1998. This time period includes the hydrology calibration time period providing assurance that the TDS calibration is accurate.

The period selected for modeling of allocation scenarios represents critical hydrological conditions. The mean daily precipitation for each season was calculated for the period January 1955 through February 2005. This resulted in 48 observations of mean precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The representative period was chosen such that the mean and variance of each season in the modeled period was not significantly different from the historical data (Table 10.1). There is no continuous USGS flow gage in the Knox Creek watershed, so the same analysis on stream flow was not possible.

Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for modeling of allocation scenarios was 10/1/1996 through 9/30/1999.

Table 10.1 Comparison of allocation modeling time period to historical records.

	Precipitation (444180/443640)			
	Fall	**Winter**	**Summer**	**Spring**
	Historical Record (1955-2005)			
Mean	3.58	4.33	3.51	4.06
Variance	80.23	100.52	66.77	119.87
	Allocation Precipitation Time Period (10/96 - 9/99)			
Mean	7.38	14.28	3.85	3.75
Variance	157.53	70.16	39.99	39.25
	p-Values			
Mean	0.304	0.027	0.465	0.469
Variance	0.151	0.498	0.447	0.278

Table 10.2 Summary of modeling time periods for Knox Creek and Pawpaw Creek.

Impairment	Hydrology Calibration - HSPF	TDS Calibration - HSPF	TDS Allocation – HSPF
Knox Creek	10/1/1994 to 9/30/1997	10/1/1993 to 9/30/1998	10/1/1996 to 9/30/1999
Pawpaw Creek	10/1/1994 to 9/30/1997	10/1/1993 to 9/30/1998	10/1/1996 to 9/30/1999

10.1.5 HSPF Sensitivity Analysis - TDS

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in TDS water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of TDS loading). An initial base run was performed during the calibration time period. Descriptions of the three parameters adjusted for the water quality sensitivity analyses with base values for the model runs given are presented in Table 10.3.

Table 10.3 Base parameter values used to determine water quality model response for Knox Creek and Pawpaw Creek watersheds.

Parameter	Description	Units	Base Value
IOQC	TDS in interflow	mg/ft^3	2,734 – 218,720
AOQC	TDS in groundwater flow	mg/ft^3	2,734 – 218,720
WSQOP	wash-off rate for TDS on land surface	in/hr	0.1

The three parameters were increased and decreased by amounts that were consistent with the range of values for the parameter. The model's responses to these changes are shown in Tables 10.4.

Table 10.4 Percent change in average monthly TDS (mg/L) for Knox Creek and Pawpaw Creek.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly TDS Geometric Mean for 1998-2003											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
IOQC	-50	-19.90	-22.22	-22.33	-18.11	-26.68	-17.37	-10.98	-9.31	-6.90	-14.51	-11.11	-16.52
IOQC	-10	-3.98	-4.44	-4.47	-3.62	-5.34	-3.47	-2.20	-1.86	-1.38	-2.90	-2.22	-3.30
IOQC	10	3.98	4.44	4.47	3.62	5.34	3.47	2.20	1.86	1.38	2.90	2.22	3.30
IOQC	50	19.90	22.22	22.33	18.11	26.68	17.37	10.98	9.31	6.90	14.51	11.11	16.52
AOQC	-50	-29.88	-27.63	-27.48	-31.70	-23.16	-32.49	-38.82	-40.35	-42.78	-35.31	-38.62	-33.25
AOQC	-10	-5.98	-5.53	-5.50	-6.34	-4.63	-6.50	-7.76	-8.07	-8.56	-7.06	-7.72	-6.65
AOQC	10	5.98	5.53	5.50	6.34	4.63	6.50	7.76	8.07	8.56	7.06	7.72	6.65
AOQC	50	29.88	27.63	27.48	31.70	23.16	32.49	38.82	40.35	42.78	35.31	38.62	33.25
WSQOP	-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WSQOP	-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WSQOP	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WSQOP	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

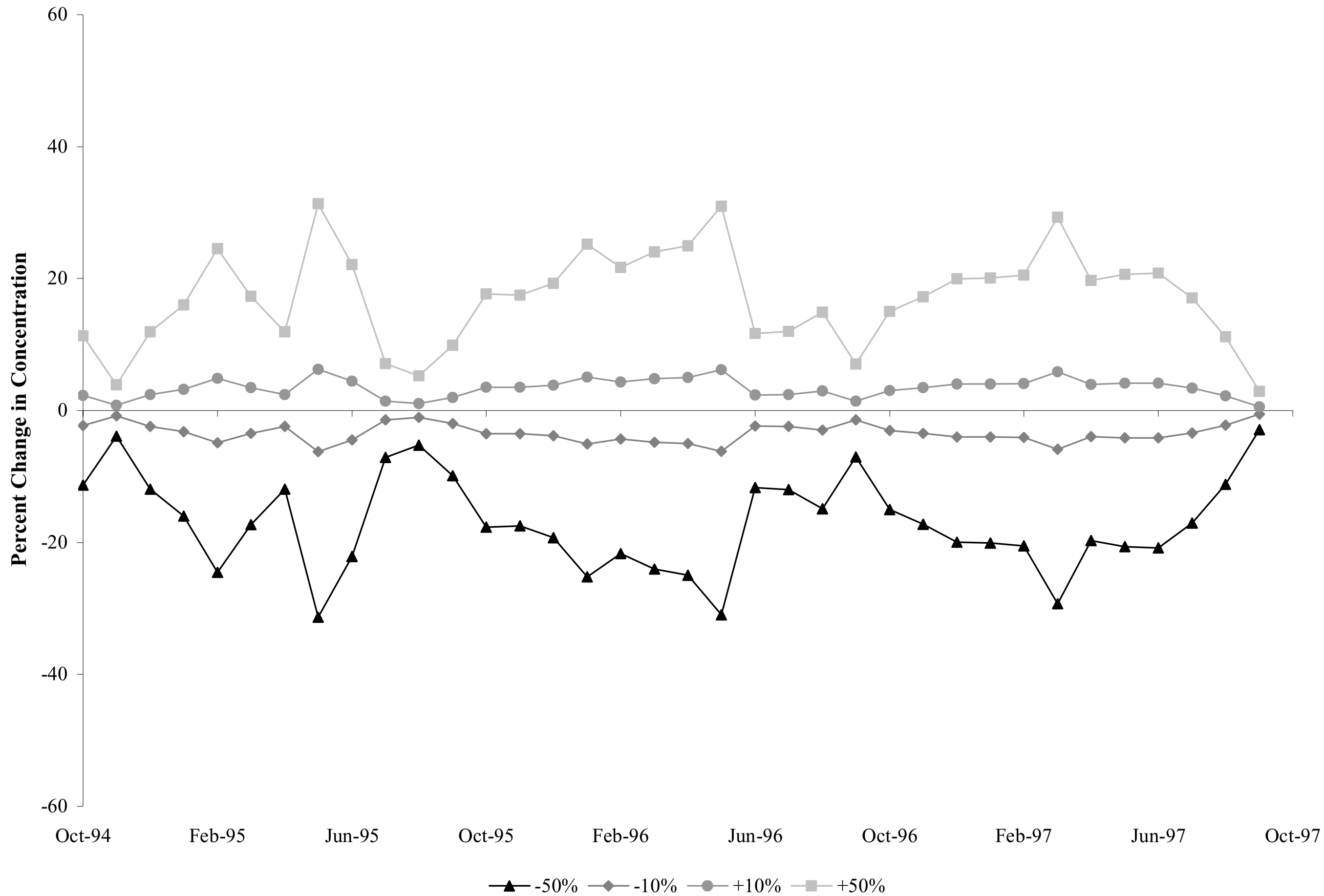

Figure 10.2 Results of sensitivity analysis on monthly concentrations in the Knox Creek watershed, as affected by changes in TDS concentration in interflow (IOQC).

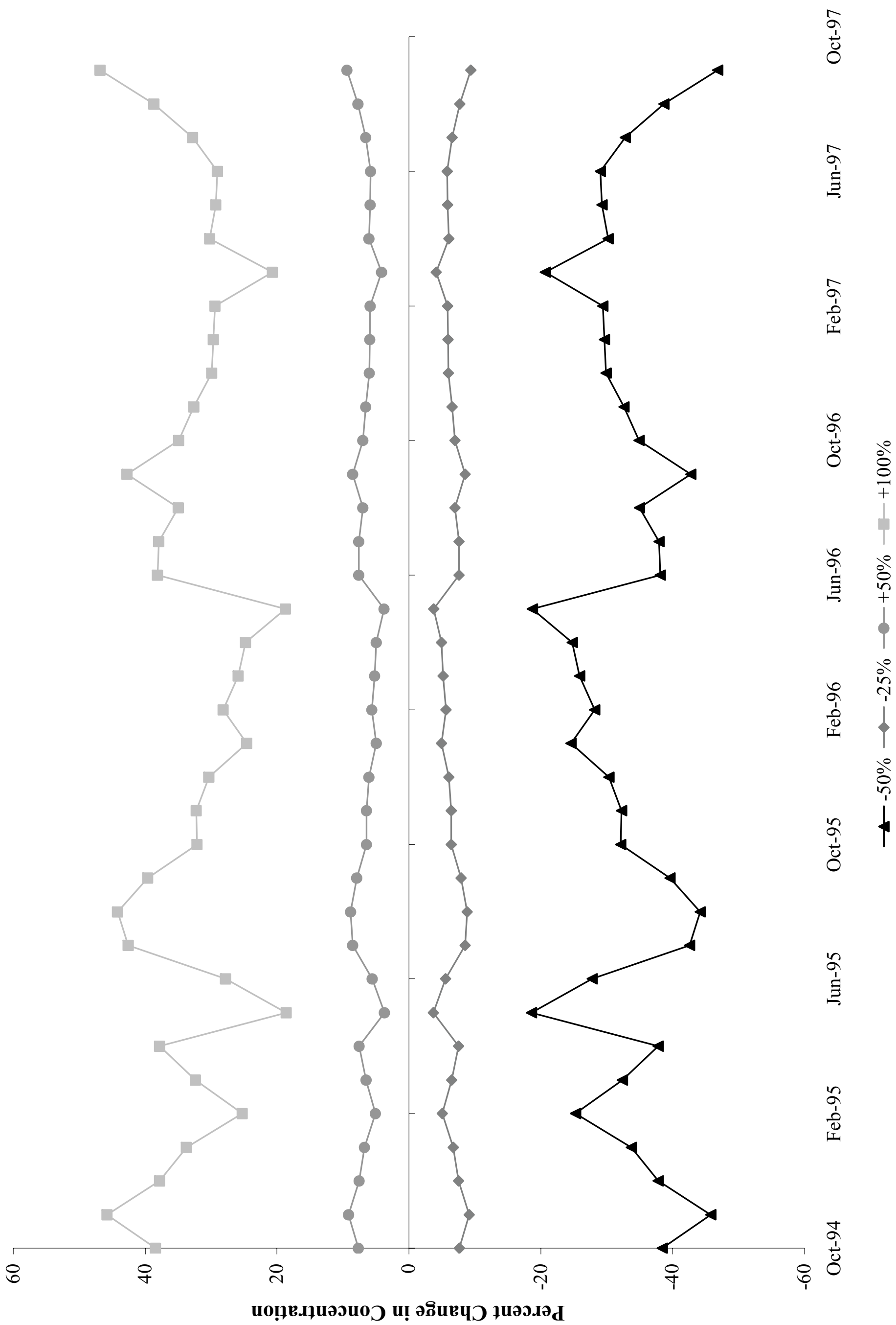

Figure 10.3 Results of sensitivity analysis on monthly concentrations in the Knox Creek watershed, as affected by changes in TDS concentration in groundwater (AOQC).

10.1.6 HSPF Model Calibration - TDS

Calibration is performed in order to ensure that the model accurately represents the water quality processes in the watershed. Hydrology calibration for Knox Creek and Pawpaw Creek was discussed in Chapter 4. Through calibration, water quality parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as TDS concentration. Additionally, the limited amount of measured data for use in calibration impedes the calibration process. The TDS calibration of Knox Creek and Pawpaw Creek was conducted using monitored data from 10/1/1994 through 9/30/1997.

Three parameters were utilized for model adjustment: concentration in interflow (IOQC), concentration in groundwater (AOQC), and rate of surface runoff of concentration from land surfaces (WSQOP). Changes in the IOQC and WSQOP parameters change TDS levels during runoff events, while changes in AOQC effect base flow TDS concentrations. All of these parameters were initially set at acceptable levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled TDS concentrations was established (Table 10.5). Careful visual inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. Results of the calibration are presented in Figures 10.4 through 10.11 from upstream to downstream.

Table 10.5 Model parameters utilized for water quality calibration of Knox Creek and Pawpaw Creek

Impairment	Parameter	Units	Initial Parameter Estimate	Calibrated Parameter Value
Knox Creek	WSQOP	in/hr	0.10	0.10
	IOQC	mg/ft^3	6,715	2,734 – 218,720
	AOQC	mg/ft^3	6,715	2,734 – 492,120
Pawpaw Creek	WSQOP	in/hr	0.10	0.10
	IOQC	mg/ft^3	6,715	2,734 – 103,892
	AOQC	mg/ft^3	6,715	2,734 – 213,252

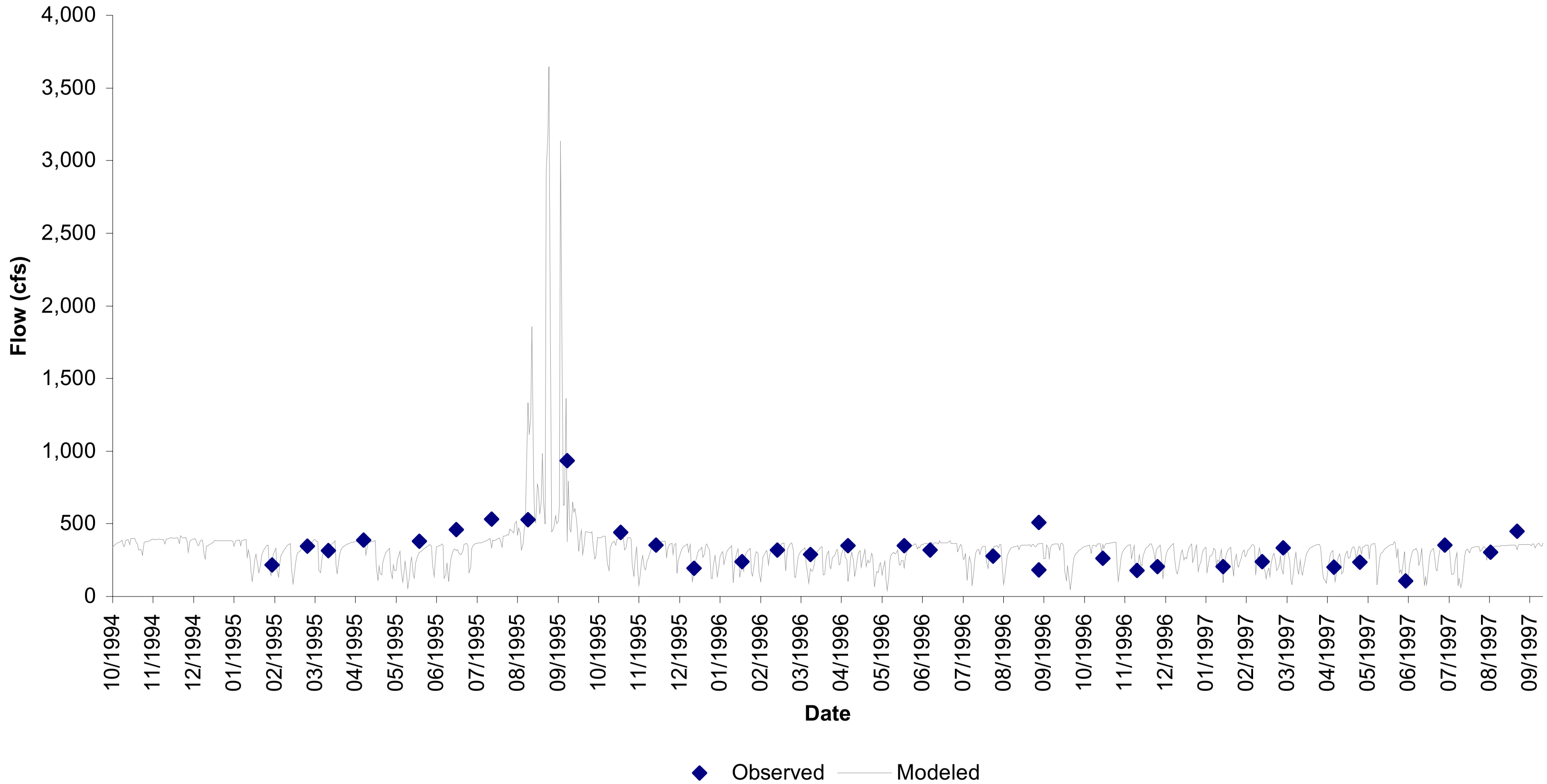

Figure 10.4 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 12 in the Knox Creek watershed, during the calibration period.

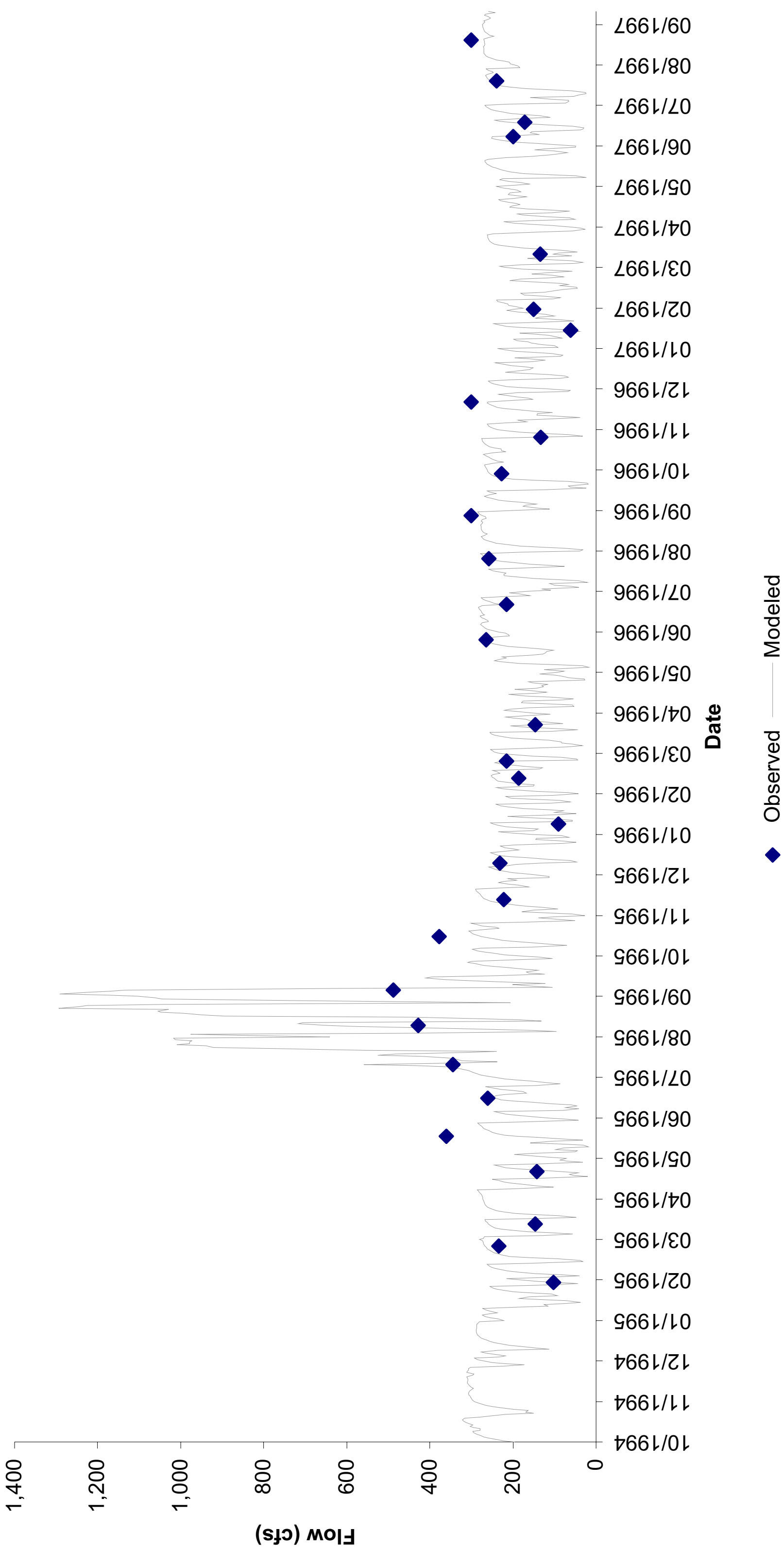

Figure 10.5 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations at the confluence of subwatersheds 4 and 16 in the Knox Creek watershed, during the calibration period.

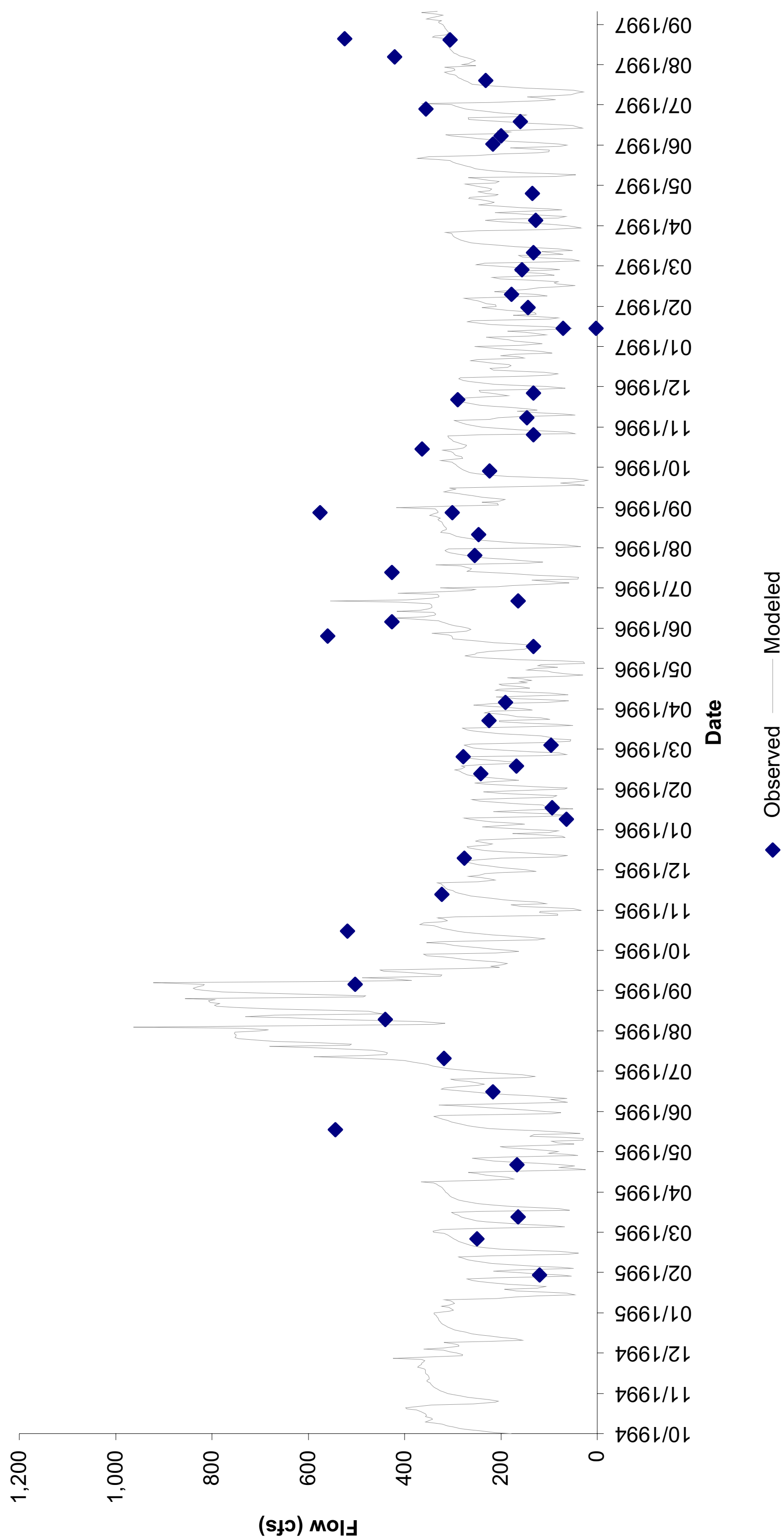

Figure 10.6 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 5 in the Knox Creek watershed, during the calibration period.

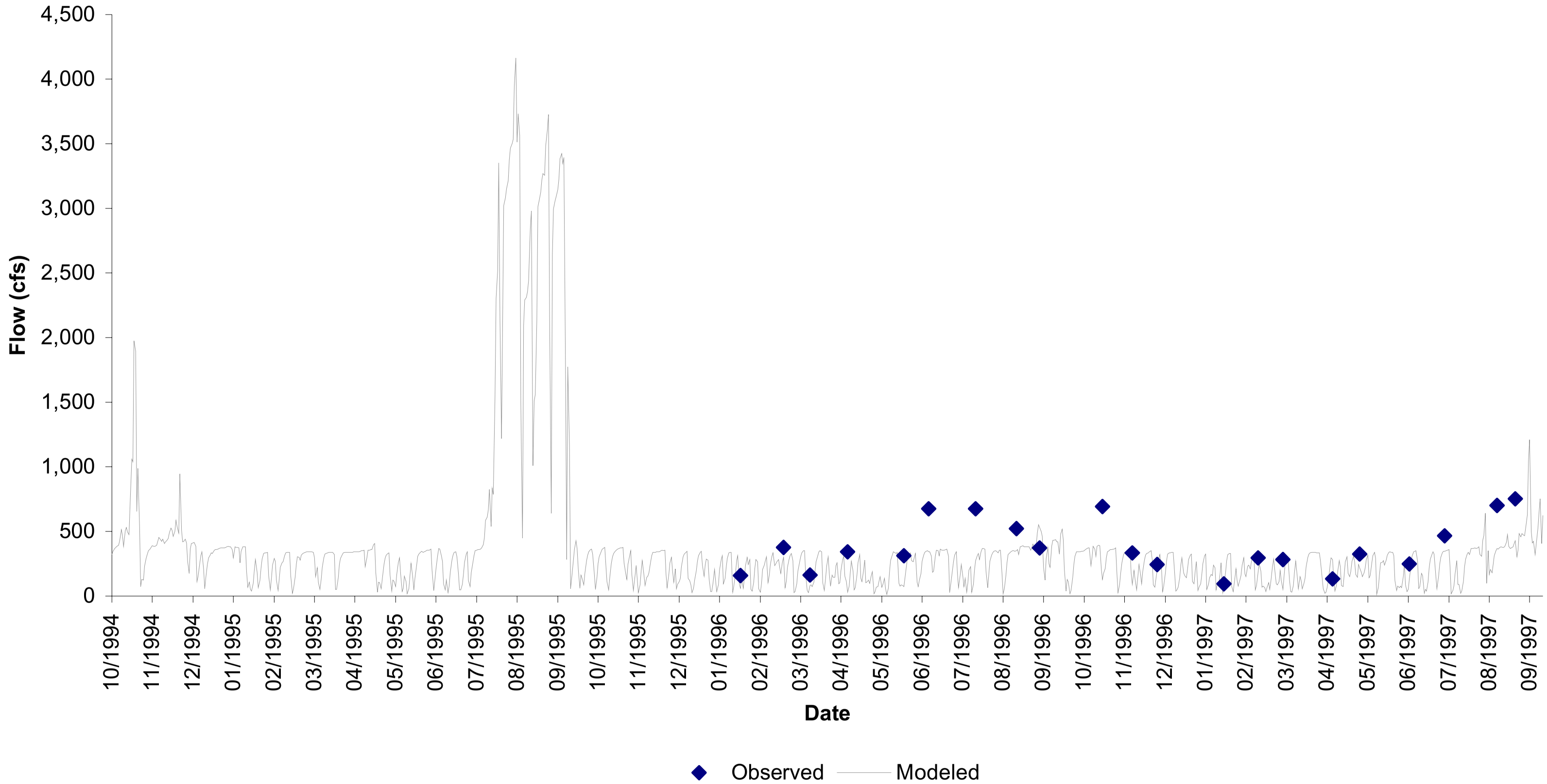

Figure 10.7 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 19 the Knox Creek watershed, during the calibration period.

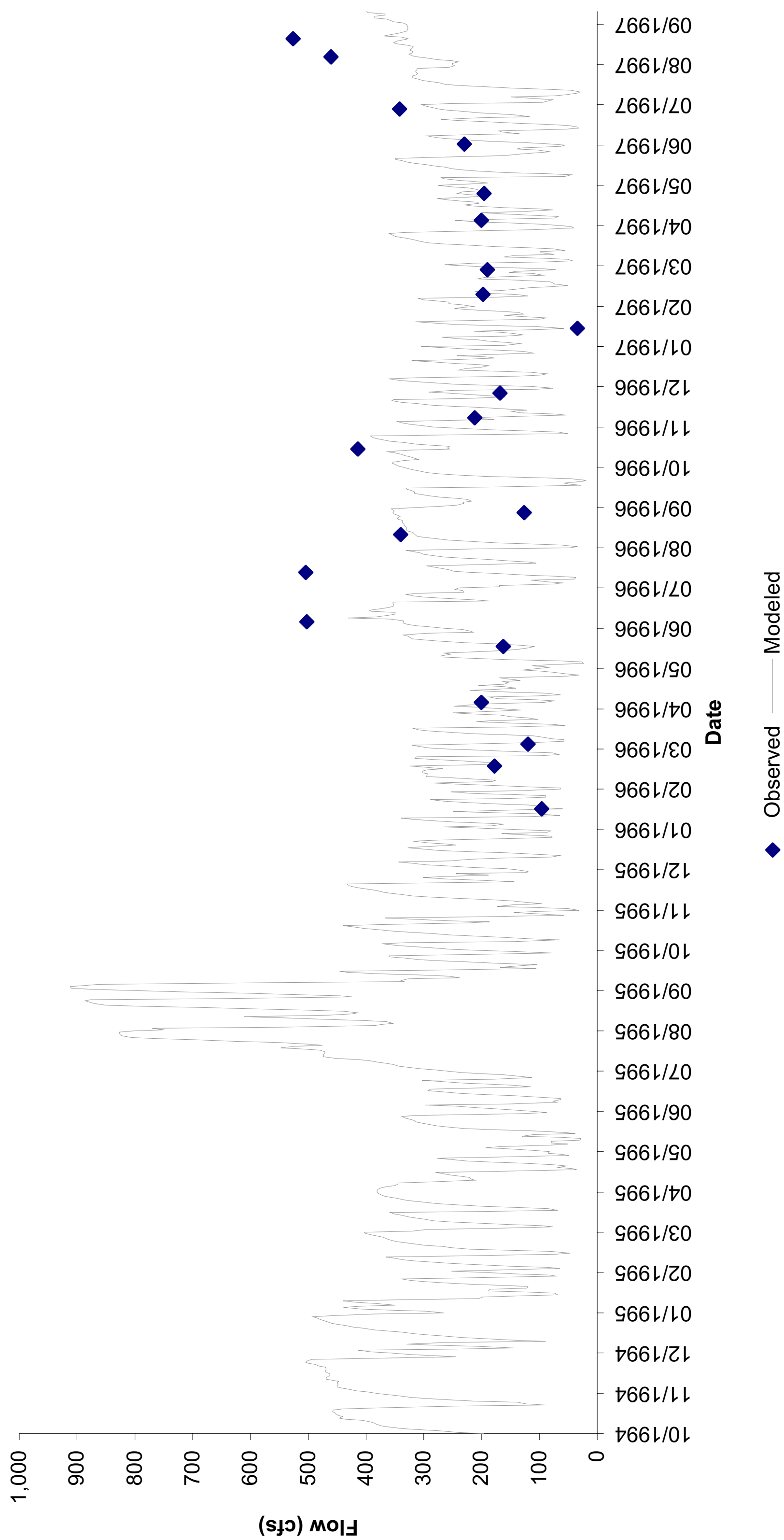

Figure 10.8 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 6 the Knox Creek watershed, during the calibration period.

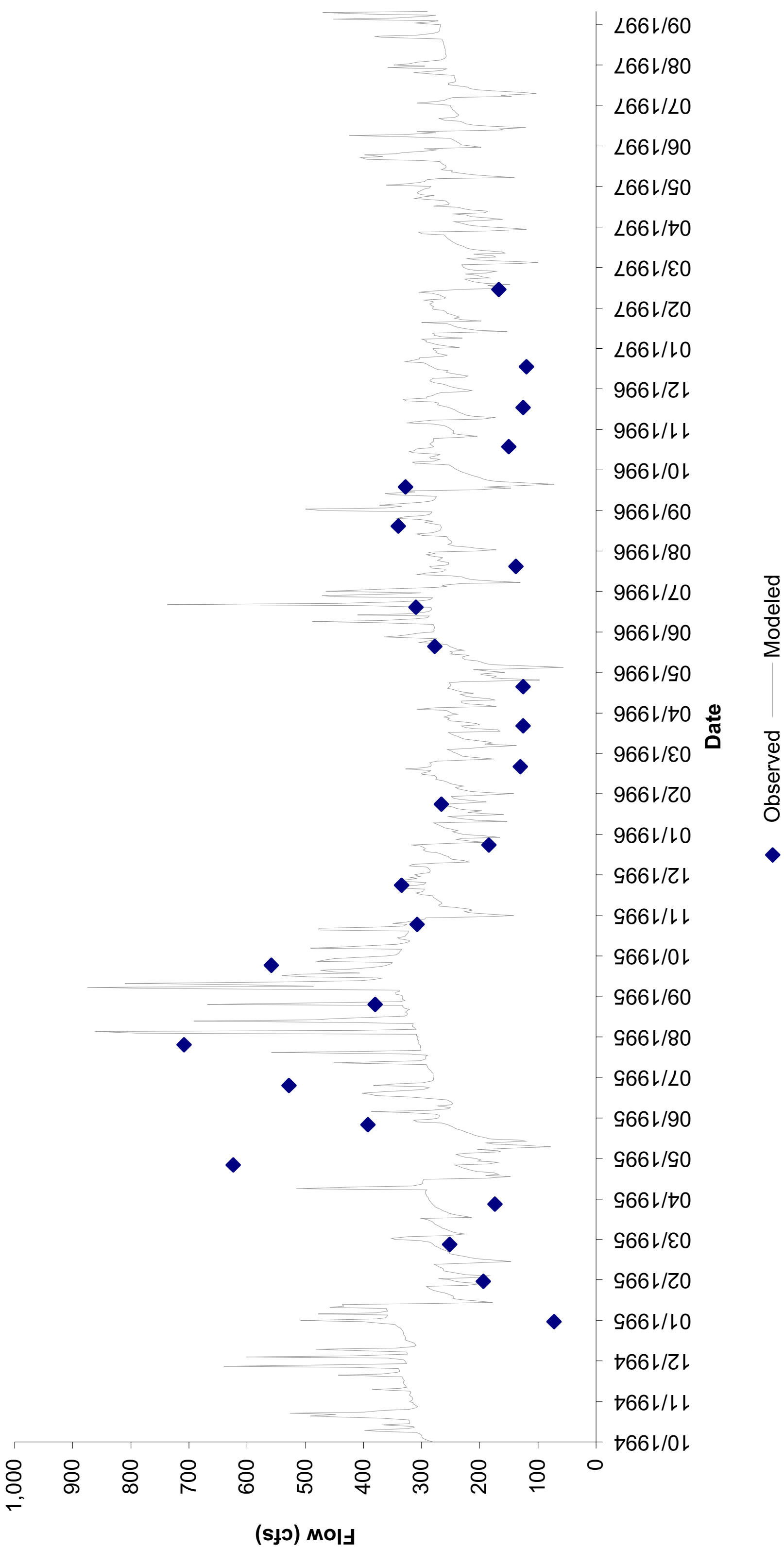

Figure 10.9 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 20 the Pawpaw Creek watershed, during the calibration period.

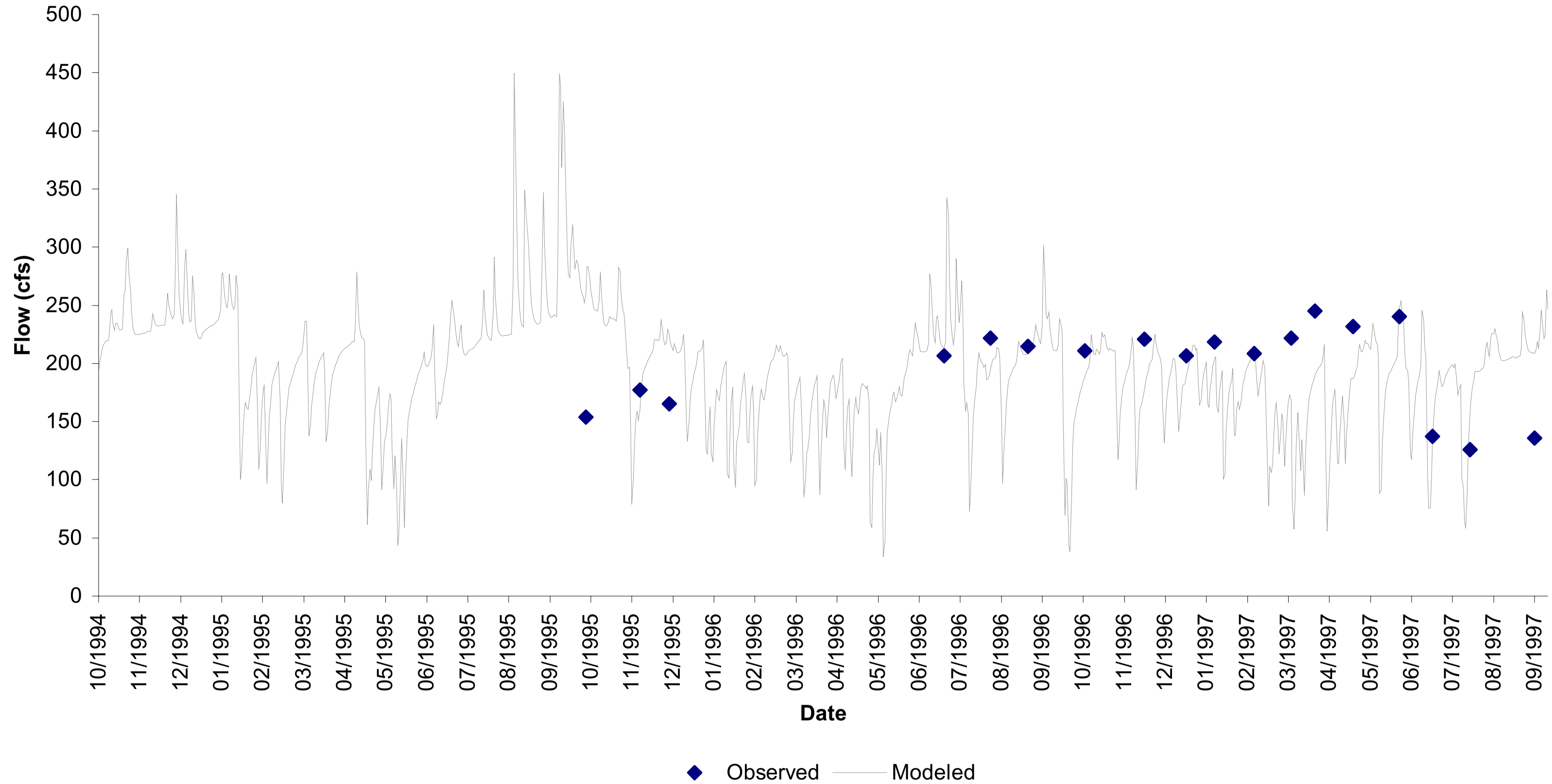

Figure 10.10 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 21 the Pawpaw Creek watershed, during the calibration period.

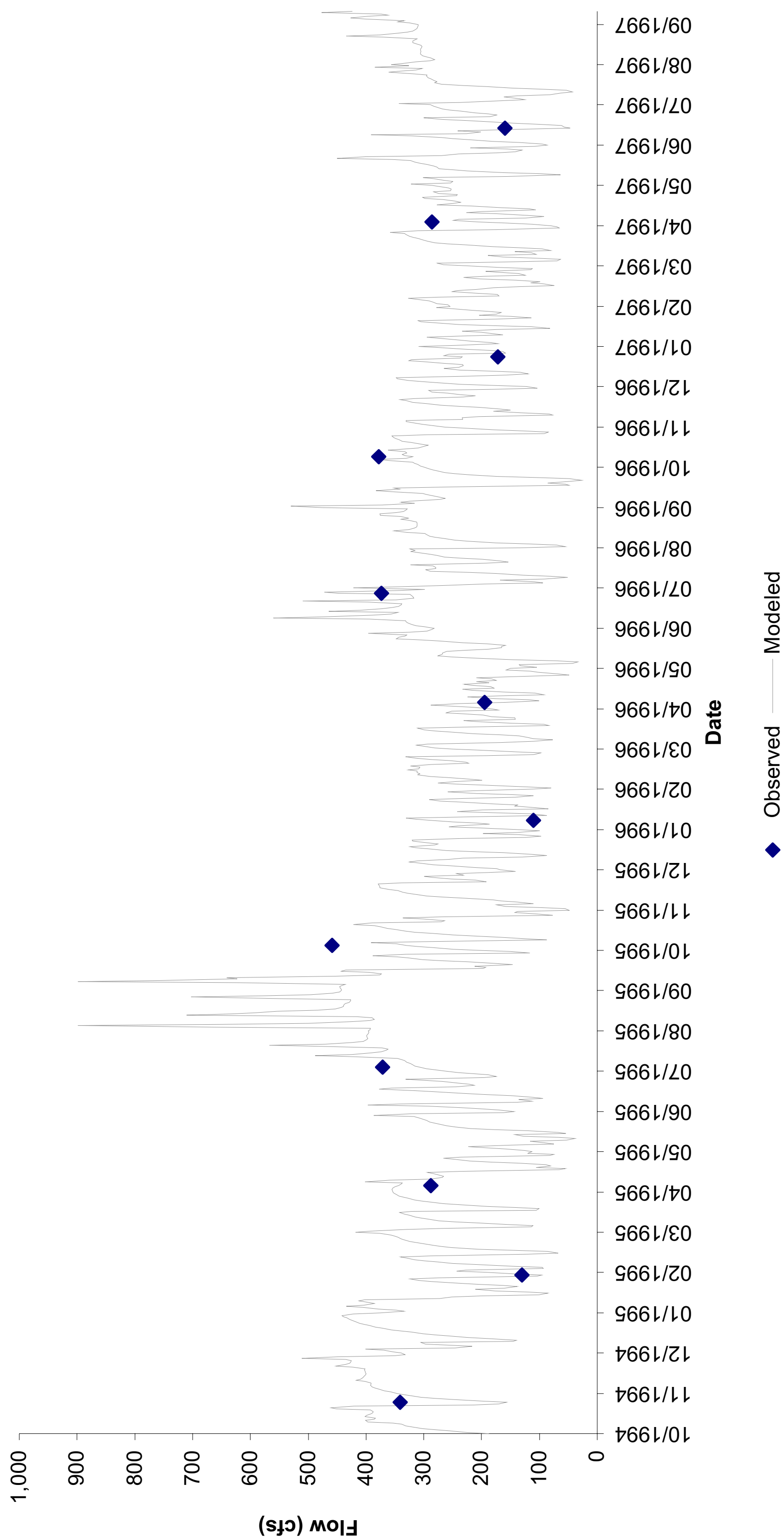

Figure 10.11 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 7 the Knox Creek watershed, during the calibration period.

10.1.7 TDS Existing Conditions

TDS point sources were updated to existing (2005) conditions to account for current flow discharges and TDS concentrations. All allocation runs started from existing conditions during the allocation time period (10/1/1996 to 9/30/1999).

10.2 Sediment – GWLF

10.2.1 Modeling Framework Selection - GWLF

A reference watershed approach was used in this study to develop a benthic TMDL for sediment for the Pawpaw Creek watershed. As noted in Chapter 7, sediment was identified as a probable stressor for Pawpaw Creek. A watershed model was used to simulate sediment loads from potential sources in Pawpaw Creek and the Middle Creek reference watershed. The model used in this study was the *Visual Basic™* version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungaged watersheds. The model also included modifications made by Yagow et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The TMDL was then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios.

GWLF is a continuous simulation, spatially lumped model that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. Land use classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, stream-bank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1981;

Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of runoff.

For execution GWLF uses three input files for weather, transport, and nutrient loads. The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in April and ending in March. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains nutrient values for the various land uses, point sources, and septic system types, and also urban sediment buildup rates.

10.2.1.1 GWLF Model Setup

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverage, local weather data, streamflow data, literature values, and other data. The watershed boundary for the Pawpaw Creek drainage area was the same used for the HSPF modeling (Chapter 4). Subwatersheds are not required to run the GWLF model. The reference watershed outlet for Middle Creek was located before the confluence of Middle Creek and the Clinch River. For the sediment TMDL development, the total area for the Middle Creek reference watershed was equated to the area of Pawpaw Creek watershed. To accomplish this, the area of land use categories in reference watershed was proportionately increased based on the percentage land use distribution. As a result, the watershed area for Middle Creek was increased to be equal to the watershed area of the Pawpaw Creek watershed.

The GWLF model was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as land use/land cover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept to estimate runoff and sediment from different pervious areas (HUs) in the watershed (Li, 1975; England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by land use activity (*e.g.,* farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses land use categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil land use topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the effect of varying soil-topographic conditions by land use entities. A description of model parameters is given in section 10.2.1.2 followed by a description of how parameters and other data were calculated and/or assembled.

10.2.1.2 Description of GWLF Model Input Parameters

The following description of GWLF model input parameters was taken from a TMDL Draft report prepared by BSE, 2003.

Hydrologic Parameters

Watershed Related Parameter Descriptions

- *Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*

- *Recession Coefficient (/day): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.*

- *Seepage Coefficient (/day): The seepage coefficient represents the amount of flow lost to deep seepage.*

Running the model for a 3-month period prior to the chosen period during which loads were calculated, initialized the following parameters.

- *Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.*

- *Initial saturated storage (cm): Initial depth of water stored in the saturated zone.*

- *Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.*

- *Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather files.*

Month Related Parameter Descriptions

- *Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*

- *ET CV: Composite evap-transpiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.*

- *Hours per Day: mean number of daylight hours.*

- *Erosion Coefficient: This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.*

Sediment Parameters

Watershed-Related Parameter Descriptions

- *Sediment Delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as the inverse function of watershed size (Evans et al., 2001).*

Land use-Related Parameter Descriptions

- *USLE K-factor (erodibility): The soil erodibility factor was calculated as an area weighted average of all component soil types.*

- *USLE LS-factor: This factor is calculated from slope and slope length.*

- *USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*

- *Daily sediment build-up rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.*

Streambank Erosion Parameter Descriptions (Evans, 2002)

- *% Developed Land: Percentage of the watershed with urban-related land uses- defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.*
- *Animal density: Calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*
- *Stream length: Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*
- *Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling, in meters.*

10.2.2 Sediment Source Assessment

Three source areas were identified as the primary contributors to sediment loading in Pawpaw Creek that are the focus of this study – surface runoff, point sources, and streambank erosion. The sediment process is a continual process but is often accelerated by human activity. An objective of the TMDL process is to minimize the acceleration process. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

10.2.2.1 Surface Runoff

During runoff events (natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.,* agricultural fields, lawns, forest.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, and land disturbance due to mining and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by various factors (*e.g.,* the deposition from wind erosion and vehicular traffic).

10.2.2.2 Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour et al., 1991; Clary and Webster, 1989; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998).

10.2.2.3 TSS Point Sources

Sediment loads from permitted wastewater, industrial, and construction stormwater dischargers, and mining operations are included in the WLA component of the TMDL, in compliance with 40 CFR§130.2(h). Fine sediments are included in TSS loads that are permitted for various facilities, industrial and construction stormwater, and VPDES permits within the Pawpaw Creek watershed. There are five types of discharges currently permitted within the Pawpaw Creek watershed: two permitted domestic sewage treatment permits, two VPDES permits, one construction stormwater permit, two carwash permits, and many DMME coal mining operation permits (Figure 3.2). There were no MS4 permits located in the Pawpaw Creek watershed.

The TSS loading from uncontrolled discharges (straight pipes) was accounted for in the GWLF model results. A TSS concentration from human waste was estimated as 320 mg/L (Lloyd, 2004).

10.2.3 Sediment Source Representation – Input Requirements

As described in section 10.2, the GWLF model was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as land use/land cover, topography, and soils. The following sections describe required inputs for the GWLF program.

10.2.3.1 Streamflow and Weather data

Daily precipitation data was available within the Knox Creek watershed at the Hurley 4S NCDC Coop station #444180 (Figure 4.1). All temperature data and the missing precipitation values were filled with values from the Grundy NCDC Coop station #443640.

Daily precipitation and temperature data was available within the Middle Creek watershed at the Richlands NCDC Coop station #447174.

10.2.3.2 Land use and Land cover

Land use areas were estimated as described in section 3.1. Land use distributions for Pawpaw Creek and the Middle Creek are given in Table 10.6. Land use acreage for the Middle Creek watershed was adjusted up by the ratio of impaired watershed to reference watershed maintaining the original land use distribution.

The weighted C-factor for each land use category was estimated following guidelines given in Wischmeier and Smith, 1978, GWLF User's Manual (Haith et al., 1992), and Kleene, 1995. Where multiple land use classifications were included in the final TMDL classification, *e.g.,* pasture/hay, each classification was assigned a C-factor and an area weighted C-factor calculated.

Table 10.6 Land use areas for the impaired, reference, and area-adjusted reference watersheds.

Sediment Source	Pawpaw Creek (ha)[1]	Reference Watershed Middle Creek (ha)	Reference Watershed Middle Creek - Area Adjusted (ha)
Pervious VA Area:			
AML	203.18		
Commercial		1.14	1.87
ActiveMine	8.12		
Cropland	6.45	13.36	21.91
Forest	3,018.00	2,622.69	4,300.22
Forest_Dist	67.73	81.11	132.99
Pasture	7.73	23.66	38.79
Reclaimed	25.59		
Reclaimed - Not permitted		98.71	161.85
Residential	0.26	12.09	19.82
Water	31.37	29.80	48.86
Pervious KY Area:			
KYAML	3.57		
KYActiveMine	46.65		
KYForest	1,284.00		
KYPasture	2.81		
KYReclaimed	10.29		
KYWater	9.85		
Impervious VA Area:			
Commercial		6.49	10.64
Salt_Roads	12.78		
Residential	0.26	1.65	2.71
Impervious KY Area:			
KYSalt_Roads	0.01		
Watershed Total	**4,739**	**2,891**	**4,740**

[1] 1ha = 2.47 ac

10.2.3.3 Sediment Parameters

Sediment parameters include USLE parameters K, LS, C, and P, sediment delivery ratio, and a buildup and loss functions for impervious surfaces. The product of the USLE parameters, KLSCP, is entered as input to GWLF. Soils data for the Pawpaw Creek and the Middle Creek were obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004). The K factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. The area-weighted K-factor by land use category was calculated using GIS procedures. Land slope was calculated from USGS National Elevation Dataset data using GIS techniques. The length-of-slope was based on VirGIS procedures given in VirGIS Interim Reports (*e.g.,* Shanholtz et al., 1988). The area-weighted LS factor was calculated for each land use category using procedures recommended by Wischmeier and Smith (1978).

10.2.3.4 Sediment Delivery Ratio

The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratios for impaired and reference watersheds were calculated as an inverse function of watershed size (Evans et al., 2001).

10.2.3.5 SCS Runoff Curve Number

The runoff curve number is a function of soil type, antecedent moisture conditions, and cover and management practices. The runoff potential of a specific soil type is indexed by the Soil Hydrologic Group (HG) code. Each soil-mapping unit is assigned HG codes that range in increasing runoff potential from A to D. The soil HG code was given a numerical value of 1 to 4 to index HG codes A to D, respectively. An area-weighted average HG code was calculated for each land use/land cover from soil survey data using GIS techniques. Runoff curve numbers (CN) for soil HG codes A to D were assigned to each land use/land cover condition for antecedent moisture condition II following GWLF guidance documents and SCS, 1986 recommended procedures. The runoff CN for each land use/land cover condition then was adjusted based on the numeric area-weighted soil HG codes.

10.2.3.6 Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of streams with livestock access, total length of natural stream channel, fraction of developed land, mean stream depth, and watershed area. The animal density was calculated by dividing the number of livestock (beef and dairy) by watershed area in acres. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The mean stream depth was estimated as a function of watershed area.

10.2.3.7 Evapo-transpiration Cover Coefficients

Evapotranspiration (ET) cover coefficients were entered by month. Monthly ET cover coefficients were assigned each land use/land cover condition following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each sediment source class.

10.2.3.8 TSS Point Sources

Construction stormwater permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/l. The modeled runoff for the construction stormwater discharge was estimated as equal to the annual runoff from the disturbed forest area. The weighted average runoff (cm) was multiplied by the permit area (ha) times permitted TSS concentration (100 mg/L) times conversion factors to get a permit load in metric tons per year (t/yr).

Table 10.7 Point Sources in the Pawpaw Creek watershed.

					Existing Conditions	Future Conditions
Permitted Mine Land	**Permit Discharge (MGD)**	**Runoff (cm/yr)**	**Area (ha)**	**Conc. (mg/L)**	**TSS (t/yr)**	**TSS (t/yr)**
	DMME Coal Mining Permits					
Active Mine Land - VA		26.28	8.12	70	0.604	0.604
Reclaimed Mine Land - VA		8.96	25.59	70	0.650	0.650
Active Mine Land - KY		26.28	46.65	70	3.473	3.473
Reclaimed Mine Land - KY		8.96	10.29	70	0.261	0.261
Total					**4.99**	**4.99**

10.2.4 Selection of Representative Modeling Period - GWLF

As described in Chapter 4, an analysis of historic precipitation and streamflow in Pawpaw Creek was preformed to select a representative time frame (Figures 4.4 and 4.5 and Table 4.5). The time period chosen was water year 1995 through water year 1997. The GWLF hydrology calibration time period was selected to coincide with the time period used for HSPF modeling, 10/1/1994 to 9/30/1997.

10.2.5 GWLF Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of land disturbance, runoff curve number, etc.). Sensitivity analyses were run on the runoff curve number (CN) and the combined erosion factor (KLSCP), which combines the effects of soil erodibility, land slope, land cover, and management practices (Table 9.1). For a given simulation, the model parameters in Table 9.1 were set at the base value except for the parameter being evaluated. The parameters were adjusted to -10%, and +10% of the base value.

Table 10.8 Base watershed parameter values used in GWLF sensitivity analysis.

	Pawpaw Creek	
Sediment Source	**CN**	**KLSCP**
Pervious VA Area:		
AML	79.22	0.53865
ActiveMine	87.25	3.96710
Cropland	81.39	4.57991
Forest	65.93	0.01464
Forest_Dist	74.01	1.17121
Pasture	71.31	0.06633
Reclaimed	74.42	0.55679
Residential	67.04	0.00474
Water	100.00	0.97651
Pervious KY Area:		
KYAML	79.22	0.53865
KYActiveMine	87.25	3.96710
KYForest	65.93	0.01464
KYPasture	71.31	0.06633
KYReclaimed	74.42	0.55679
KYWater	100.00	0.97651
Impervious VA Area:		
Salt_Roads	98.00	0.02690
Residential	98.00	0.00237
Impervious KY Area:		
KYSalt_Roads	98.00	0.34599

The results in Table 10.9 show that the parameters are directly correlated with runoff and sediment load. The relationships show fairly linear responses, with outputs being more sensitive to changes in CN than KLSCP. The results tend to reiterate the need to carefully evaluate conditions in the watershed and follow a systematic protocol in establishing values for model parameters.

Table 10.9 Sensitivity of GWLF model response to changes in selected parameters for Pawpaw Creek.

Model Parameter	Parameter Change (%)	Total Runoff Volume (%)	Total Sediment Load (%)
CN	10	4.87	16.97
CN	-10	-3.98	-29.77
KLSCP	10	0	10.00
KLSCP	-10	0	-10.00

10.2.6 GWLF Hydrology Calibration

Although the GWLF model was originally developed for use in ungaged watersheds, calibration was performed to ensure that hydrology was being simulated accurately. This process was preferred in order to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soils, land use, and topographic data. Parameters that were adjusted during calibration included the recession constant, the evapotranspiration cover coefficients, the unsaturated soil moisture storage, and the seepage coefficient.

10.2.6.1 Middle Creek – Reference Stream

The final GWLF calibration results for the Middle Creek are displayed in Figures 10.12 and 10.13 for the calibration period with statistics showing the accuracy of fit given in the Table 9.5.

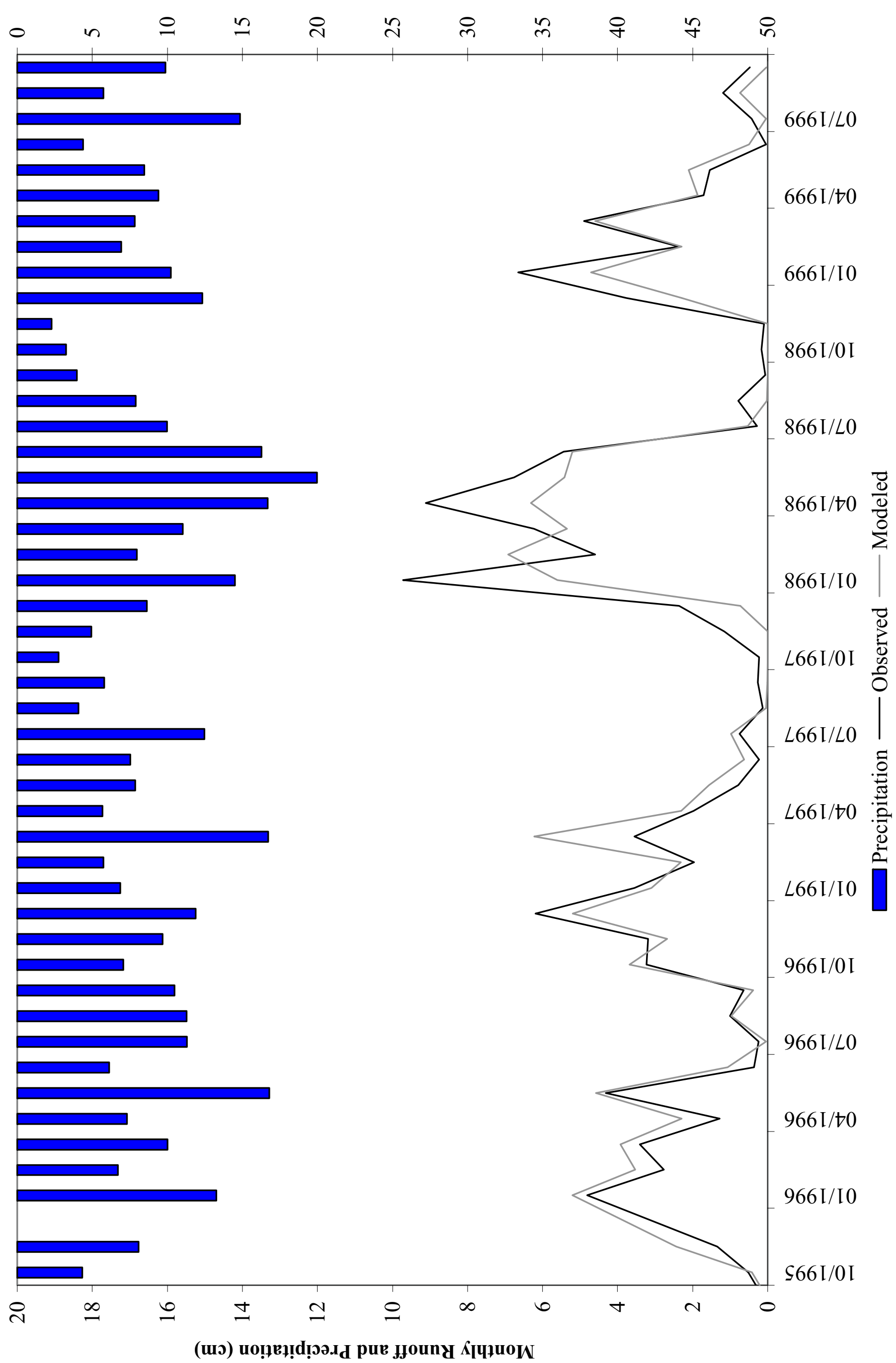

Figure 10.12 Comparison of monthly GWLF simulated (Modeled) and monthly HSPF simulated (Observed) for Middle Creek.

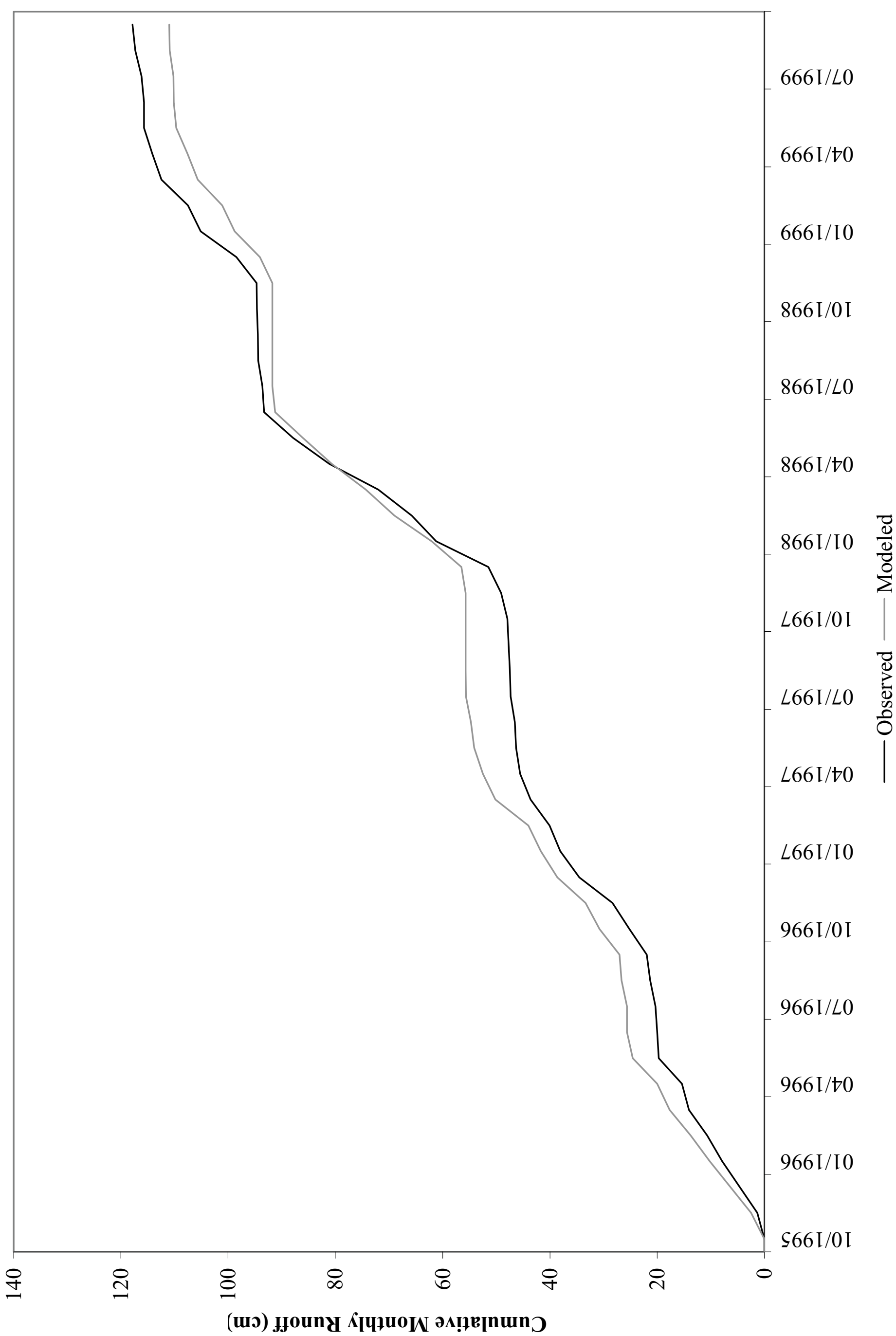

Figure 10.13 Comparison of cumulative monthly GWLF simulated (Modeled) and cumulative HSPF simulated (Observed) for Middle Creek.

10.2.6.2 Pawpaw Creek – Impaired Stream

The final GWLF calibration results for Pawpaw Creek are displayed in Figures 10.14 and 10.15 for the calibration period with statistics showing the accuracy of fit given in the Table 10.5.

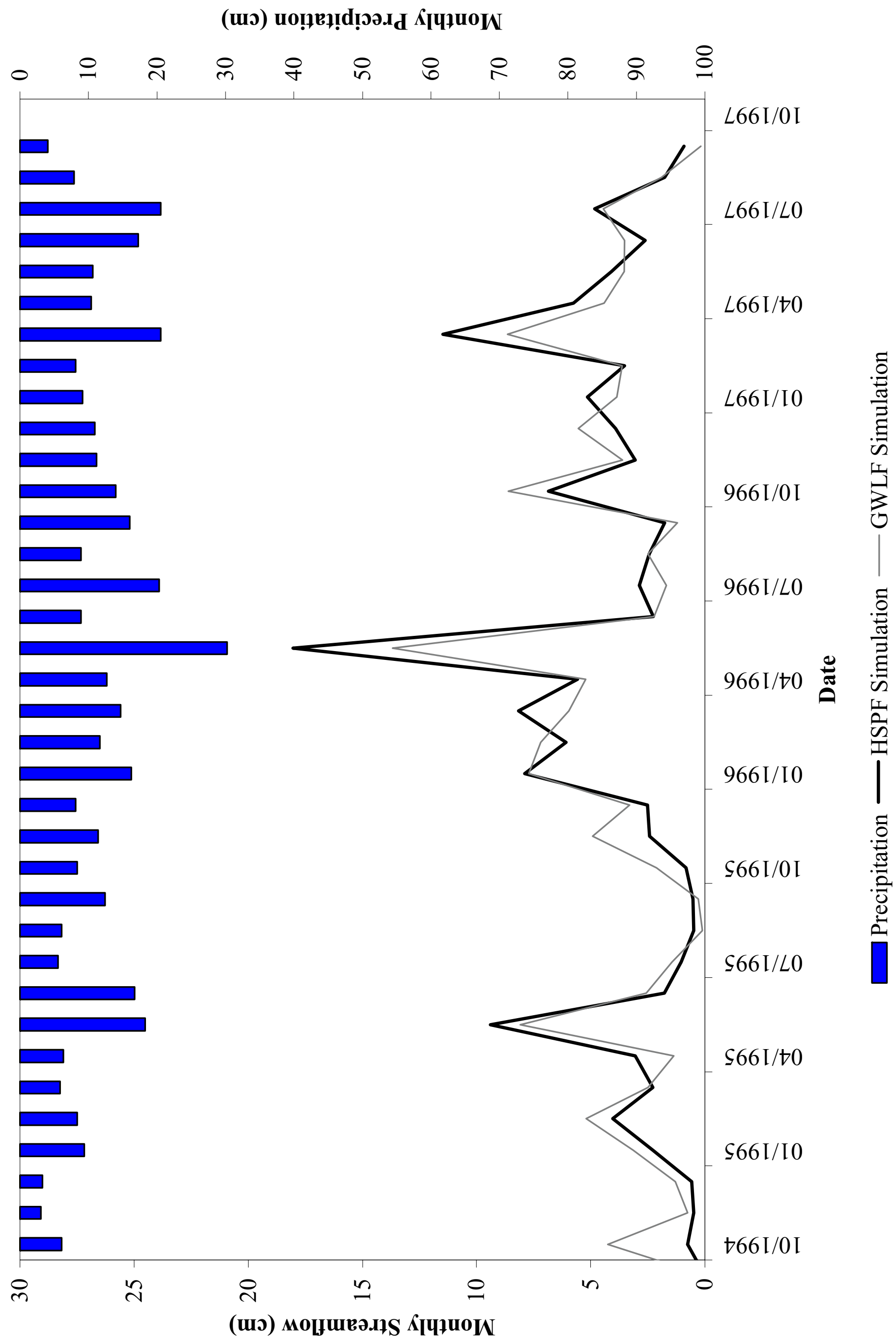

Figure 10.14 Comparison of monthly GWLF simulated (Modeled) and monthly HSPF simulated (Observed) for Pawpaw Creek.

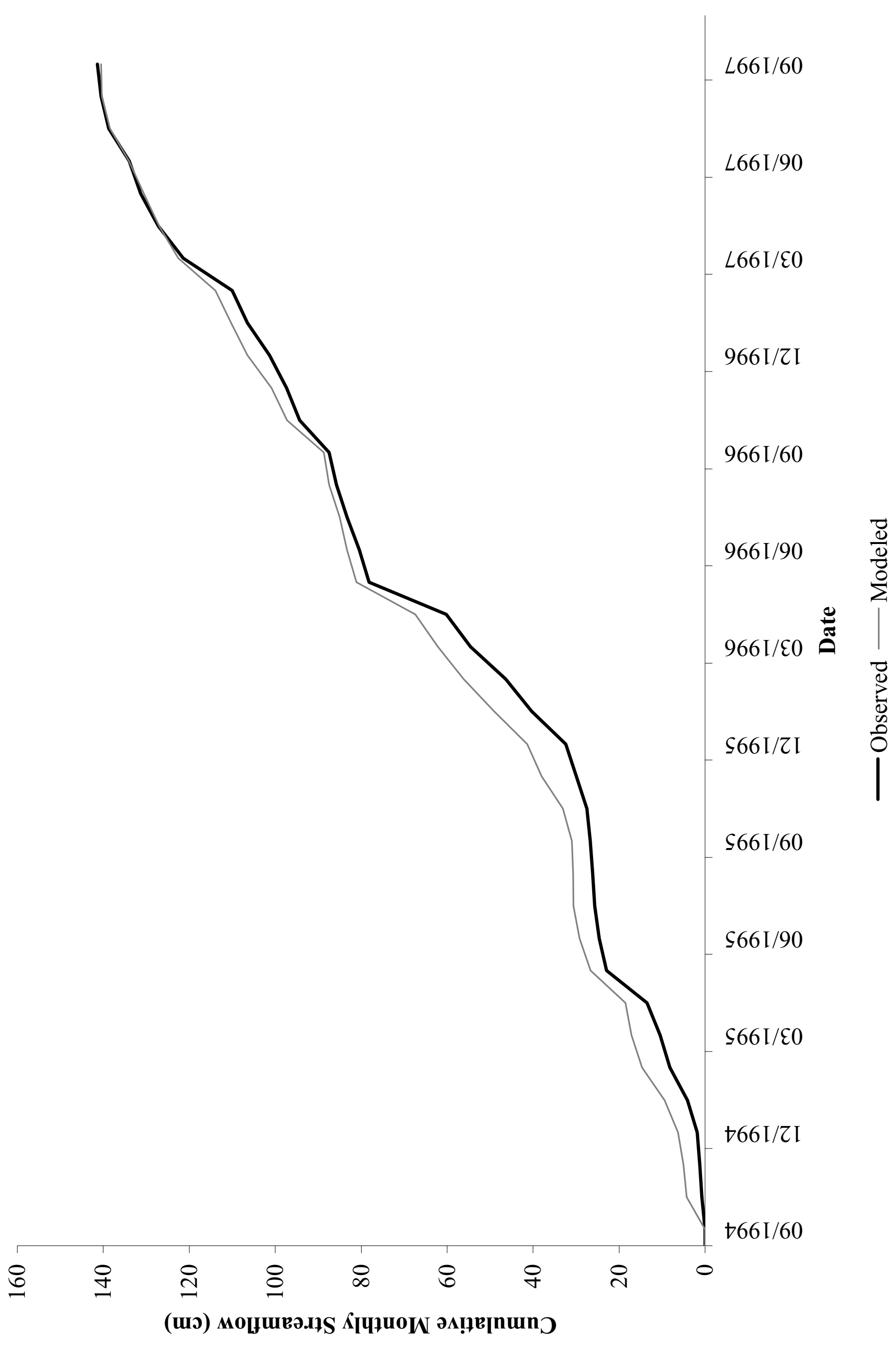

Figure 10.15 Comparison of cumulative monthly GWLF simulated (Modeled) and cumulative HSPF simulated (Observed) for Pawpaw Creek.

10.2.6.3 GWLF Hydrology Calibration Statistics

Model calibrations were considered good for total runoff volume (Table 10.10). Monthly fluctuations were variable but were still reasonable considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.,* Tetra Tech, 2002 and BSE, 2003).

Table 10.10 GWLF flow calibration statistics for Pawpaw Creek and Middle Creek.

Watersheds	Simulation Period	R^2 Correlation value	Total Volume Error (Sim-Obs)
Pawpaw Creek	10/1/1994 to 9/30/1997	0.922	-0.603
Middle Creek	10/1/1995 to 9/30/1999	0.893	-0.058

10.2.7 Sediment Existing Conditions

A listing of parameters from the GWLF transport input files that were finalized during hydrologic calibration for existing conditions are given in Tables 10.11 through 9.9. Watershed parameters for Pawpaw Creek and reference watershed Middle Creek are given in Table 9.6. Monthly evaporation cover coefficients are listed in Table 9.7.

Table 10.11 GWLF watershed parameters for existing conditions in the calibrated impaired and reference watersheds.

GWLF Watershed Parameter	Units	Pawpaw Creek	Middle Creek
Recession Coefficient	Day^{-1}	0.052	0.052
Seepage Coefficient	Day^{-1}	0.0525	0.062
Sediment Delivery Ratio	---	0.15	0.13
Unsaturated Water Capacity	(cm)	7.44	7.44
Erosivity Coefficient (Apr-Sep)	---	0.25	0.25
Erosivity Coefficient (Oct-Mar)	---	0.06	0.06
% Developed land	(%)	0.297	0.225
Livestock density	(AU/ac)	0.000438	0.000355
Area-weighted soil erodibility (K)	---	0.221	0.270
Area weighted runoff curve number	---	67.35	68.90
Total Stream Length	(m)	20,042	15,840
Mean channel depth	(m)	0.73	0.88

Table 10.12 Pawpaw Creek and reference watershed Middle Creek GWLF monthly evaporation cover coefficients for existing conditions.

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Pawpaw Creek	0.58	0.60	0.92	0.78	0.78	0.78	0.78	0.76	0.75	0.75	0.75	0.56
Middle Creek	0.68	0.70	0.82	0.88	0.88	0.71	0.70	0.66	0.65	0.65	0.65	0.66

Table 10.13 lists the area-weighted USLE erosion parameter and runoff curve number by land use erosion source areas for Pawpaw Creek and the reference watershed Middle Creek.

Table 10.13 GWLF land use parameters for existing conditions in the impaired and reference watersheds.

	Pawpaw Creek		Middle Creek	
Sediment Source	**CN**	**KLSCP**	**CN**	**KLSCP**
Pervious VA Area:				
AML	79.22	0.53865		
Commercial			93.67	0.0253
ActiveMine	87.25	3.96710		
Cropland	81.39	4.57991	80.80	3.0938
Forest	65.93	0.01464	65.05	0.0135
Forest_Dist	74.01	1.17121	73.37	1.0803
Pasture	71.31	0.06633	70.63	0.0358
Reclaimed	74.42	0.55679		
Reclaimed - Not permitted			65.38	0.5100
Residential	67.04	0.00474	70.30	0.0110
Water	100.00	0.97651	100.00	1.3405
Pervious KY Area:				
KYAML	79.22	0.53865		
KYActiveMine	87.25	3.96710		
KYForest	65.93	0.01464		
KYPasture	71.31	0.06633		
KYReclaimed	74.42	0.55679		
KYWater	100.00	0.97651		
Impervious VA Area:				
Commercial			98.00	1.0103
Salt_Roads	98.00	0.02690		
Residential	98.00	0.00237	98.00	0.0055
Impervious KY Area:				
KYSalt_Roads	98.00	0.34599		

The area adjustments for the reference watershed compared to Pawpaw Creek are listed in Table 10.6.

The sediment loads existing at the time of impairment were modeled for Pawpaw Creek and the reference watershed Middle Creek. The existing condition for the Pawpaw Creek watershed is the combined sediment load, which compares to the area-adjusted reference watershed Middle Creek load under existing conditions (Table 10.14).

Table 10.14 Existing sediment loads for the impaired and area-adjusted reference watersheds.

Sediment Source	Pawpaw Creek		Reference Watershed Middle Creek Area-Adjusted	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious VA Area:				
AML	4,289	21.1		
Commercial	-	-	1.59	0.85
ActiveMine	0.60	0.18		
Cropland	1,211	187.7	1,667	76
Forest	1,257	0.42	603.0	0.1
Forest_Dist	2,799	41.3	2,832	21
Pasture	17.06	2.21	20.94	0.54
Reclaimed	0.65	0.063		
Reclaimed - Not permitted	-	-	857.3	5.3
Residential	0.144	0.139	3.26	0.16
Water	0	0	0	0
Pervious KY Area:				
KYAML	75.36	21.11		
KYActiveMine	3.47	0.18		
KYForest	535.2	0.42		
KYPasture	6.20	2.21		
KYReclaimed	0.26	0.06		
KYWater	0.00	0.00		
Impervious VA Area:				
Commercial	-	-	2.30	0.22
Salt_Roads	3.06	0.24		
Residential	0.062	0.24	0.58	0.22
Impervious KY Area:				
KYSalt_Roads	0.00	0.00		
Streambank Erosion (VA & KY)	81.44	-	45.79	0.00
Straight pipes (VA only)	2.94	-	0.00	0.00
Point Sources (VA only)	4.99	-	0.00	0.00
Watershed Total	**10,287**		**6,034**	

11. ALLOCATION

Total Maximum Daily Loads consist of waste load allocations (WLAs, permitted point sources) and load allocations (LAs, nonpoint sources), including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for uncertainties in the process. The definition is typically denoted by the expression:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS}$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For TDS, the TMDL is expressed in terms of loads (kg/yr). For sediment, the TMDL is expressed in terms of annual load in metric tons per year (t/yr).

This section describes the development of TMDLs for TDS for Knox Creek and TDS and sediment for Pawpaw Creek using a reference watershed approach. The 90^{th} percentile TDS concentration of 369 mg/L measured in Dismal Creek was used as the TDS TMDL endpoint for Knox Creek. The 90^{th} percentile TDS concentration of 334 mg/L (based on 10 samples) measured in Middle Creek was used as the TDS TMDL endpoint for Pawpaw Creek. The average annual sediment load from the Middle Creek reference watershed was used to define the sediment TMDL loads for the Pawpaw Creek watershed.

11.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. For the TDS model by allocating permitted point sources at the maximum allowable fecal coliform concentration and selecting a modeling period that represented the critical hydrologic conditions in the watershed the MOS is an implicit MOS. For the sediment model an explicit MOS of 10% was used.

11.2 TDS TMDL

11.2.1 Scenario Development

The allocation scenario was modeled using HSPF. Existing conditions were adjusted until the TMDL endpoint was attained. The TMDL developed for Pawpaw Creek was based on the 90th percentile TDS concentration (334 mg/L) sampled in Middle Creek. The 90th percentile TDS concentration of 369 mg/L measured in Dismal Creek was used as the TDS TMDL endpoint for Knox Creek. An 10% implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the endpoint was met. The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

11.2.1.1 Wasteload Allocations

Two deep mine discharges in the Knox Creek watershed were operational during the water quality calibration period (Figure 9.1). There are currently two VPDES permits for fecal control, two carwash permits, and two general permits for residential sewage treatment discharge. These permitted point sources, which have flows that are not directly driven by rainfall events, were modeled as flowing directly into the stream network, as described in Chapter 10.

The DMME permits associated with surface mining in these watersheds were modeled as NPS loads since a runoff event is required to deliver pollutants to the stream from these sources. These sources are considered to be transient as they are temporary best management practices (*e.g.*, ponds) installed to control NPS pollution resulting from active surface mining operations. Upon completion of current mining operations, these ponds will likely be removed and additional ponds installed as new operations begin. As such, the wasteload allocation developed for Knox Creek and Pawpaw Creek includes a "transient" load, which represents the acceptable load from these sources.

11.2.1.2 Load Allocations

Load allocations (LA) to nonpoint sources are divided into land-based loadings from land uses and non-permitted loads applied directly in the stream (*e.g.,* uncontrolled residential discharges). The TDS loads from straight pipes were modeled as a direct source, but they are not permitted so these loads are included in the LA. Source reductions include those that are affected by both high and low flow conditions. In-stream TDS concentrations are highest during low flow conditions, but TDS concentrations spike during extreme rainfall events (high flow due to runoff).

11.2.1.3 Knox Creek

Scenarios were modeled with Pawpaw Creek allocated for TDS (Section 11.2.1.4) because Pawpaw Creek flows into Knox Creek; therefore the TDS load from Pawpaw Creek affects the TDS load in portions of Knox Creek. The TDS load in Knox Creek was not sensitive to the two deep mine discharges modeled (MPID1431 and MPID6070139). Scenarios were made by reducing the TDS loads from all land uses except forest and reclaimed land, until the modeled TDS concentration for the modeling period was less than or equal to the target TDS concentration. Table 11.1 shows the existing conditions and final allocated loads for the Knox Creek watershed. The final allocation scenario included a 100% reduction in straight pipes due to the results of the fecal bacteria TMDL.

Table 11.1 Source loads used in Knox Creek model runs.

Source	Total Annual Loading for Existing Run (kg/yr)	Total Annual Loading for Allocation Run (kg/yr)
Land Based	1.83E+07	7.97E+06
Direct	2.0E+04	1.0E+04

11.2.1.4 Pawpaw Creek

Scenarios were made by reducing the TDS loads from all land uses except forest and reclaimed land, until the modeled TDS concentration for the modeling period was less than or equal to the target TDS concentration. Table 11.2 shows the existing conditions and final allocated loads for the Pawpaw Creek watershed. The final allocation scenario included a 100% reduction in straight pipes due to the results of the fecal bacteria TMDL. All the direct TDS sources in the Pawpaw Creek watershed during the allocation time period were straight pipes.

Table 11.2 Source loads used in Pawpaw Creek model runs.

Source	Total Annual Loading for Existing Run (kg/yr)	Total Annual Loading for Allocation Run (kg/yr)
Land Based	3.33E+06	2.71E+06
Direct	2.0E+04	0.0

11.2.2 Knox Creek Final TDS TMDL

Table 11.3 shows the final TMDL loads for the Knox Creek TDS impairment. The permitted discharges are listed under the lumped load for WLA allocation. These included deep mine discharges and surface mine ponds active during the modeling time period (Table 11.3). Figure 11.1 show the existing and allocated conditions at the outlet of Knox Creek.

Table 11.3 Average annual TDS loads (kg/yr) modeled after TMDL allocation in the Knox Creek impairment.

Allocation	Description	TDS (kg/year)
Waste Load Allocation[1]		**1.11E+06**
Permit Number:	MPID	
1401358	*6070139*	
1200159/1201641	*1431*	
VA0026972		
VA0067521		
VAG400180		
VAG400391		
Transient Loads[2]		
1100279	*5880524,5880526 - 5880528,5880531 - 5880535*	
1100321	*6080573*	
1101400	*6070142 - 6070158*	
1101550	*2024 - 2031*	
1200034	*6082883, 6082884*	
1200038	*6082893 - 6082896*	
1200101/1201637	*6083006*	
1200158/1201646	*6083112*	
1200202	*6083177*	
1200840	*6084226 - 6084228*	
1201085	*6084523*	
1201238	*6070095*	
1201275	*5670260*	
1201303/1201706	*6070116*	
1201501/1201708	*1359*	
1201527/1201709	*1744*	
1300114/1301728	*6084597*	
1300160/1301657	*6084617, 6084618*	
1300191/1301644	*6084627, 6084628*	
1300229/1301714	*6084657 - 6084663*	
1300236	*6084668*	
1300261/1301712	*6084682, 6084683*	
1300558	*6085096, 6085097*	
1300236/1301723/1301727	*6070104, 6070105*	
1400190	*6085543*	
1401242	*6070098 - 3070101*	
1401255	*6070106 - 6070108*	
1401312	*1768, 5670329 - 5670331*	
1401358	*6070132 - 6070139*	
1401570/1401734/1601089	*6086035, 6086036*	
Load Allocation		**6.85E+06**
TMDL		**7.97E+06**

[1] TDS from WLA is presented as a combined load from all permitted sources.
[2] The waste load from runoff-controlling BMPs (*i.e.,* ponds) that are likely to be removed upon completion of current mining operations.

The loads from all land uses impacted by anthropogenic activity (*i.e.,* non-forest and non-wetland areas) were calibrated to meet existing conditions in the stream, and equal reductions were modeled for all land uses impacted by anthropogenic activity. Given the limited amount of data available for parsing the anthropogenic load among known sources, no attempt was made to determine specific load reduction requirements for specific sources.

The waste load allocation was thus established based on overall reductions for the watershed. This approach established an equitable WLA and LA but did not establish a required reduction from permitted sources. At this time, there is not enough water quality and other data on the permitted sources to calculate or model with confidence an existing TDS loading for these facilities. During implementation, the existing permitted sources will be monitored to determine their existing load. Needed reductions cannot be calculated until those data have been collected.

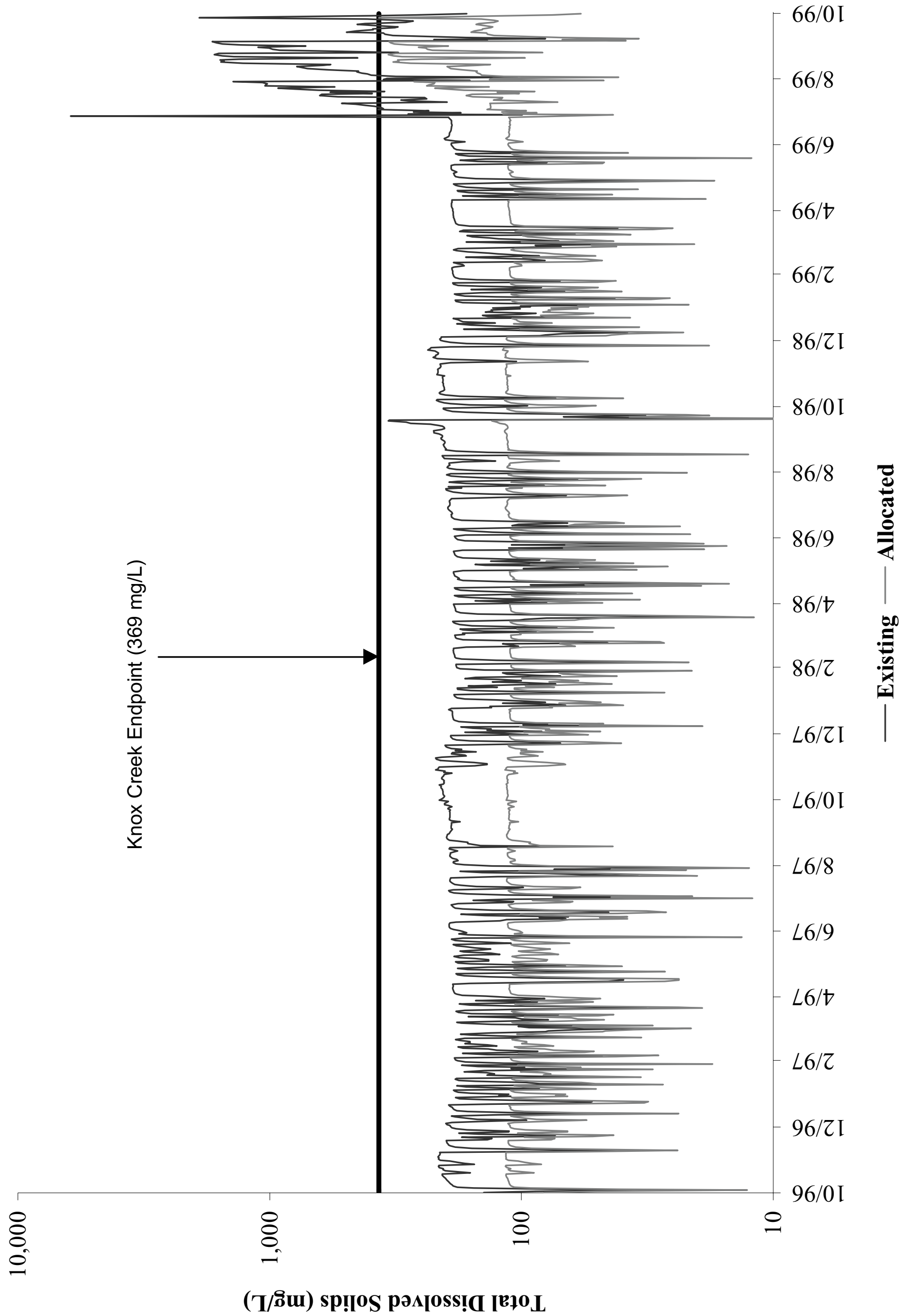

Figure 11.1 TDS concentrations for the Knox Creek impairment under existing and allocated conditions at the outlet.

11.2.3 Pawpaw Creek Final TDS TMDL

Table 11.4 shows the final TMDL loads for the impairments. The permitted discharges are listed under the lumped load for WLA allocation. These included all deep mine discharges and surface mine ponds. These permit numbers are the current permits in the watersheds (Table 11.4). Figure 11.2 show the existing and allocated conditions at the outlet of Pawpaw Creek.

Table 11.4 Average annual TDS loads (kg/yr) modeled after TMDL allocation in the Pawpaw Creek impairment.

Allocation	Description	TDS (kg/year)
Waste Load Allocation[1]		**1.52E+05**
Transient Loads[2]		
Permit Number:	MPID	
1100572	*6081252,6081253*	
1101530	*1758 - 1760*	
1200025	*6082875*	
1200036/1201729	*5670028*	
1200619	*6083817*	
1200619/1201715	*6083816*	
1201070/1201733	*6084487, 6084488*	
1201404	*6070165*	
Load Allocation		**2.56E+06**
TMDL		**2.71E+06**

[1] TDS from WLA is presented as a combined load from all permitted sources.
[2] The waste load from runoff-controlling BMPs (*i.e.,* ponds) that are likely to be removed upon completion of current mining operations.

The loads from all land uses impacted by anthropogenic activity (*i.e.,* non-forest and non-wetland areas) were calibrated to meet existing conditions in the stream, and equal reductions were modeled for all land uses impacted by anthropogenic activity. Given the limited amount of data available for parsing the anthropogenic load among known sources, no attempt was made to determine specific load reduction requirements for specific sources.

The waste load allocation was thus established based on overall reductions for the watershed. This approach established an equitable WLA and LA but did not establish a required reduction from permitted sources. At this time, there is not enough water quality and other data on the permitted sources to calculate or model with confidence an existing TDS loading for these facilities. During implementation, the existing permitted sources will be monitored to determine their existing load. Needed reductions cannot be calculated until those data have been collected.

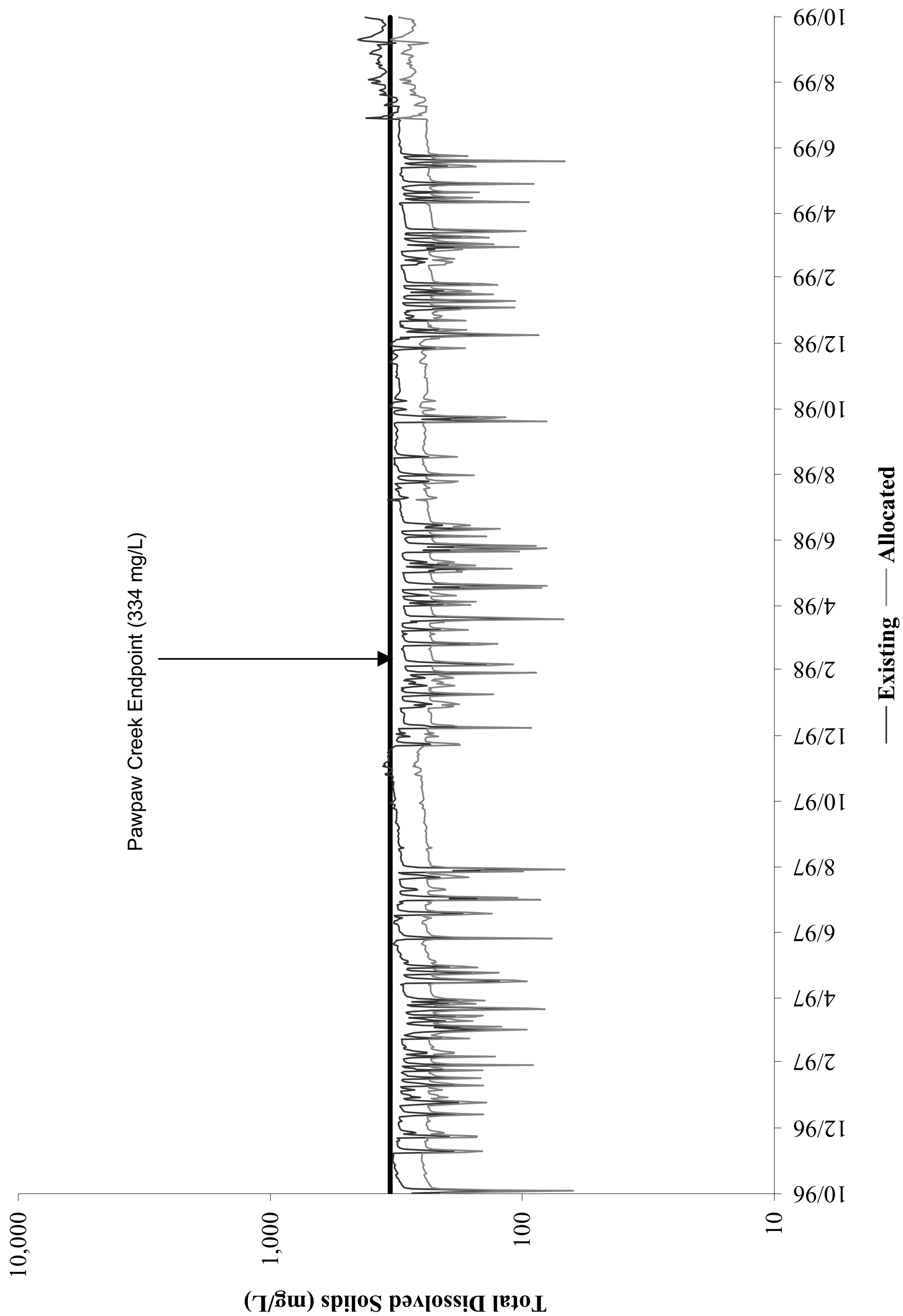

Figure 11.2 TDS concentrations for the Pawpaw Creek impairment under existing and allocated conditions at the outlet.

11.2.4 Future Reductions and Future Growth

Before imposing future reductions on permitted sources, VADEQ will reopen and validate or amend the TMDL and subsequently the WQMP regulation, if needed. Amendments may include the quantification of existing loads, % reduction overall or by source subcategory, individual allocations and adjustments of any allocation.

As part of any TMDL reopener, VADEQ will validate or amend, based on all available data and information, its original assumptions about (a) TDS as a most probable stressor; (b) 334 mg/l as the proper water quality target; and (c) the model outputs. To ensure consistency with existing TMDL modification guidance (Guidance Memo 05-2011, VADEQ 2005), if the TMDL reopener occurs in response to a request for additional waste load allocation(s), any cost incurred by the TMDL re-evaluation and remodeling effort will be paid for by the applicant.

New permitted point source discharges will be allowed under the waste load allocation provided they implement applicable VPDES or Virginia Coal Surface Mining Reclamation Regulation (CSMRR) requirements (including any BMP, offset, trading or payment-in-lieu conditions established to meet any future reduction requirements).

Unless and until VADEQ reopens and revises the TMDL to impose TDS waste load allocations on permitted sources (or categories of sources), new dischargers will be subject to monitor-only requirements, together with whatever permit-based requirements DMME will impose pursuant to the CSMRR.

11.3 Sediment TMDL

This section describes the development of a TMDL for sediment for Pawpaw Creek using a reference watershed approach. The model was run over the period of 10/1/1996 to 9/30/1999 for modeling sediment allocations for Pawpaw Creek. The target sediment TMDL load for Pawpaw Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Middle Creek watershed under existing conditions minus a Margin of Safety (MOS).

11.3.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The MOS for the Pawpaw Creek sediment TMDL was explicitly expressed as 10% of the area-adjusted reference watershed load (603.37 t/yr).

11.3.2 Future Land Development Considerations

A review of the Buchanan County Comprehensive Plan (Buchanan County Board of Supervisors, 1994) indicated that land use is not expected to change significantly over the next 25 years. Pawpaw Creek watershed is highly rural and it is assumed that residential and commercial growth in the watershed will not have an impact on future sediment loads. However, increased mining operations could have an impact if sediment control ponds exceed the permitted 70mg/L.

11.3.3 Final Sediment TMDL

The target TMDL load for Pawpaw Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Middle Creek watershed under existing conditions. To reach the TMDL goal (5,430 t/yr), three different scenarios were run with GWLF (Table 11.5). Sediment loads from straight pipes were reduced 100% in all scenarios due to health implications and the requirements of the fecal bacteria TMDL. Scenario 1 shows similar reductions to sediment loads from abandoned mine land (59%), disturbed forest (58%), and high tillage cropland (57%), and a 13% reduction to streambank erosion. Scenario 2 shows reductions to loads from only abandoned mine land (69%), disturbed forest (68%). Scenario 3 shows to decrease the reduction requirement from high tillage cropland from 57% to 56%, the reduction from streambank erosion must be 28%. That is more than double the reduction in Scenario1. All three scenarios meet the TMDL goal at a total sediment load reduction of 47.2%. Scenario 1 was chosen to use for the final TMDL because it has similar reductions on three land uses with less emphasis on reducing streambank erosion than Scenario 3.

Although the streambank erosion load is the combined load from the Virginia and Kentucky portions of the stream, the required 13% reduction shown in Scenario 1 can be implemented in the Virginia portion of the watershed only. Since only 35% of the mainstem of the stream network is in the Kentucky portion of the watershed, it is reasonable to estimate the 13% sediment reduction required in Scenario 1 can be obtained from BMPs implemented in the Virginia portion of the watershed.

Table 11.5 Final TMDL allocation scenario for the impaired watershed.

Sediment Source	Pawpaw Existing Loads t/yr	Scenario 1 Reductions (Final) (%)	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions (%)	Scenario 2 Loads t/yr	Scenario 3 Reductions (%)	Scenario 3 Loads t/yr
Pervious VA Area:							
AML	4,289	59	1,758	69	1,330	59	1,758
ActiveMine	0.60	0	0.60	0	0.60	0	0.60
Cropland	1,211	57	520.5	0	1,211	56	532.65
Forest	1,257	0	1,257	0	1,257	0	1,257
Forest_Dist	2,799	58	1,176	68	895.8	58	1,176
Pasture	17.06	0	17.06	0	17.06	0	17.06
Reclaimed	0.65	0	0.65	0	0.65	0	0.65
Residential	0.14	0	0.14	0	0.14	0	0.14
Water	0.00	0	0.00	0	0.00	0	0.00
Pervious KY Area:							
KYAML	75.36	0	75.36	0	75.36	0	75.36
KYActiveMine	3.47	0	3.47	0	3.47	0	3.47
KYForest	535.18	0	535.18	0	535.18	0	535.18
KYPasture	6.20	0	6.20	0	6.20	0	6.20
KYReclaimed	0.26	0	0.26	0	0.26	0	0.26
KYWater	0.00	0	0.00	0	0.00	0	0.00
Impervious VA Area:							
Salt_Roads	3.06	0	3.06	0	3.06	0	3.06
Residential	0.06	0	0.06	0	0.06	0	0.06
Impervious KY Area:		0	0.00	0	0.00	0	0.00
KYSalt_Roads	0.00	0	0.00	0	0.00	0	0.00
Streambank Erosion (VA & KY)	81.44	13	70.85	0.0	81.44	28	58.64
Straight pipes (VA only)	2.94	100	0.00	100	0.00	100	0.00
Point Sources (VA only)	4.99	0	4.99	0	4.99	0	4.99
Watershed Total	10,287	47.2	5,430	47.3	5,422	47.2	5,430

The sediment TMDL for Pawpaw Creek includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point source discharges. The LA was calculated as the target TMDL load minus the WLA load minus the MOS.

Table 11.6 TMDL targets for the impaired watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS (t/yr)	TMDL (t/yr)
Pawpaw Creek	4.99	5,425	603.4	6,034

The final overall sediment load reduction required for Pawpaw Creek is 47.2% (Table 11.7).

Table 11.7 Required reductions for the impaired watershed.

Load Summary	Pawpaw Creek	Reductions Required	
	(t/yr)	(t/yr)	(% of existing load)
Existing Sediment Loads	10,287	4,857	47.2
Target Modeling Load	5,430		

PART IV: IMPLEMENTATION AND PUBLIC PARTICIPATION

12. IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments in the Knox Creek watershed. The second step is to develop a TMDL Implementation Plan (IP). The final step is to implement the TMDL IP, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by the EPA and then the State Water Control Board (SWCB), measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the Implementation Plan. The process for developing an implementation plan has been described in the *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

VADCR and VADEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable implementation plan that will result in meeting the water quality target. Since this TMDL consists of NPS load allocations originating from mining activities, DMME will share responsibilities with VADCR during implementation.

12.1 Staged Implementation

Implementation of BMPs in these watersheds will occur in stages. The benefit of staged implementation is that it provides a mechanism for developing public support and for evaluating the efficacy of the TMDL in achieving the water quality standard.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas, the most promising management practice to control bacteria and minimize streambank erosion is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock hooves has been shown to reduce bank erosion.

Additionally, in both urban and rural areas, reducing the human bacteria loading from uncontrolled discharges (straight pipes) and failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on proper sewage disposal systems, septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage I scenarios are targeted at controllable, anthropogenic bacteria sources.

12.1.1 Staged Implementation – Bacteria – Knox Creek

The goal of the Stage 1 scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios.

The goal of the Stage 1 scenario is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10 percent. The Stage 1 scenario was generated with the same model setup as was used for the TMDL allocation scenarios (Table 12.1). Table 12.2 Scenario 1 details the load reductions required for meeting the Stage 1 Implementation for Knox Creek.

Table 12.1 Bacteria reduction scenarios for Knox Creek.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife Loads	NPS Forest/ Wetlands	Direct Livestock Loads	NPS Agricultural Land	Direct Human Loads	NPS Residential Land	Geometric Mean > 126 cfu/100ml	Single Sample > 235 cfu/100ml
1[1]	0	0	89	98	100	98	25.00	9.51
2[2]	87	94	89	99.5	100	99.5	0.00	0.00

[1]Stage 1 implementation scenario.
[2]Final TMDL allocation.

Table 12.2 Fecal coliform land-based loads deposited on all land uses and direct loads in the Knox Creek watershed for existing conditions and for the Stage 1 implementation management scenario.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Active	7.71E+12	7.71E+12	0
AML	9.54E+12	9.54E+12	0
Cropland	1.09E+13	2.18E+11	98
Forest	3.94E+14	3.94E+14	0
LAX	3.72E+12	7.44E+10	98
Pasture	1.15E+14	2.30E+12	98
Reclaimed	3.34E+12	3.34E+12	0
Residential	1.14E+15	2.28E+13	98
Salted_Roads	8.63E+12	8.63E+12	0
KYActive	1.37E+12	1.37E+12	0
KYAML	1.34E+11	1.34E+11	0
KYCropland	1.30E+09	1.30E+09	0
KYForest	3.61E+13	3.61E+13	0
KYPasture	2.47E+10	2.47E+10	0
KYReclaimed	2.98E+11	2.98E+11	0
KYSalted_Roads	2.76E+09	2.76E+09	0
KYWater	4.74E+12	4.74E+12	0
Direct			
Human - VA	1.63E+13	0.00E+00	100
Human - KY	9.85E+11	9.85E+11	0
Wildlife - VA	2.22E+13	2.22E+13	0
Wildlife - KY	9.70E+11	9.70E+11	0
Livestock - VA	2.87E+11	3.15E+10	89

12.1.2 Staged Implementation – Benthic – Knox Creek and Pawpaw Creek

It is anticipated that AML and disturbed forest along with the correction of straight pipes will be the initial targets of implementation. Table 12.3 shows a 34% reduction from both AML and disturbed forest and a 100% reduction of TSS from straight pipes results in a 23.5% reduction in the sediment load, which is near half of the required overall reduction. Streambank buffers, improved pasture management, and runoff diversion systems are BMPs that will help prevent sediment from these land uses from traveling to the stream. The goal of the Stage 1 scenario in Table 12.3 was to reduce the sediment in Pawpaw Creek to half of the TMDL goal.

Table 12.3 Sediment reduction scenarios for Pawpaw Creek.

Sediment Source	Pawpaw Existing Loads t/yr	Stage 1 Reductions (%)	Stage 1 Loads t/yr
Pervious VA Area:			
AML	4,289	34	2,831
ActiveMine	0.60	0	0.60
Cropland	1,211	0	1,210.6
Forest	1,257	0	1,257
Forest_Dist	2,799	34	1,848
Pasture	17.06	0	17.06
Reclaimed	0.65	0	0.65
Residential	0.14	0	0.14
Water	0.00	0	0.00
Pervious KY Area:			
KYAML	75.36	0	75.36
KYActiveMine	3.47	0	3.47
KYForest	535.18	0	535.18
KYPasture	6.20	0	6.20
KYReclaimed	0.26	0	0.26
KYWater	0.00	0	0.00
Impervious VA Area:			
Salt_Roads	3.06	0	3.06
Residential	0.06	0	0.06
Impervious KY Area:		0	0.00
KYSalt_Roads	0.00	0	0.00
Streambank Erosion (VA & KY)	81.44	0	81.44
Straight pipes (VA only)	2.94	100	0.00
Point Sources (VA only)	4.99	0	4.99
Watershed Total	**10,287**	**23.5**	**7,875**

One way to accelerate reclamation of AML is through remining. As noted on the DMME website (DMME, 2004):

> *"DMME, The Nature Conservancy, Virginia Tech/Powell River Project, and the U. S. Office of Surface Mining combined resources to develop proposals for incentives that will promote economically viable,*

> *environmentally beneficial remining operations that reclaim AML sites. Initial meetings led to the development of a Remining Ad Hoc Work Group that includes representatives from industry, other governmental agencies, special interest groups, and citizens of Southwest Virginia. The Ad Hoc Group has identified existing incentives and continues to propose new ones".*

One of the most important existing incentives is the alternative effluent limitations assigned to remining operations with pre-existing pollutant discharges. These regulations (known as the Rahall Amendment) were the result of a 1987 revision to the Federal Clean Water Act (CWA). Alternate effluent discharge limits are allowed in coal mining areas with pre-existing effluent problems. Operators document effluent conditions prior to remining. Upon completion of the remining operation and prior to reclamation bond and permit release, the operator would need to demonstrate that the pollution load from the site is equal to or less than pre-mining pollution load. Because the remining revisions were promulgated after the original TMDL provisions of the CWA, pollution load allocations and implementation plans should be designed to preserve the incentives implicit in the Rahall Amendment. Potential remining site include all abandoned mine land (AML).

Streambank stabilization in conjunction with riparian buffers will be useful in addressing both the TDS and sediment issues. Streambank stabilization will allow the development of a riparian zone, and will also reduce sediment delivery from the eroding streambank. TDS is associated with sediment delivery to the stream and the resulting increase in sediment/water contact. Decreasing streambank erosion problems should consequently have a beneficial impact on TDS as well as sediment levels. Riparian buffers slow surface water movement, allowing sediment to settle out before reaching the stream. In addition, to the degree that surface runoff is allowed to infiltrate as a result of being detained in the riparian zone, fine particulate matter will be captured in the soil matrix before entering the stream.

Through the remining process in Knox Creek, combined with streambank stabilization and development of riparian buffers, there exists reasonable assurance that the pollution load reductions proposed in the TMDL can be achieved. Some of the best supporting data on pollution load reductions resulting from successful remining operations are included with the EPA's remining document.

In 1998, the Pennsylvania Department of Environmental Protection (PADEP) developed a remining database to determine the success of Pennsylvania's remining program. The database specifically quantifies the extent to which bituminous coal remining sites have reduced pollution loads from the pre-existing conditions. Evaluations of the data were made by comparing pre-mining and post-mining loads at individual discharges for several parameters. The results are included in a report, broken down by stressor or pollutant. The database includes water quality information from more than 200 remining sites. BMPs used at the remining sites were common to surface mining activities throughout the Appalachian region and included daylighting deep mines, regrading, revegetation, and alkaline soil addition. The BMPs did not include chemical treatment, constructed wetlands, or long term treatment mechanisms. The PADEP results document that load reductions on the order of 60 to 70% were measured for pollutants of interest. When the observed pollution reductions associated with the remining process are compared to the modeled load reductions needed to improve Knox and Pawpaw Creeks, the recommended reductions for the stream appear attainable.

Waste load allocations and pollution load reductions necessary for active mining operations to meet TMDLs in watersheds where benthic stressors have been identified as suspended and dissolved solids, may be achieved with sediment control measures and BMPs instead of altered effluent limitations on permitted point source discharges.

Virginia's CSMRRs require active mining operations to use sediment control measures and BMPs to prevent additional contributions of solids to stream flow and to minimize erosion to the extent possible. The measures include practices carried out within and adjacent to the disturbed mining area and consist of the utilization of proper mining and reclamation methods and control practices, singly or in combination. These methods and practices include, but are not limited to:

1) Disturbing the smallest area at any one time during the mining operation through progressive backfilling, grading, and prompt revegetation;
2) Stabilizing the backfill material to promote a reduction in the rate and volume of runoff;
3) Diverting runoff away from disturbed areas;
4) Directing water and runoff with protected channels;
5) Using straw, mulches, vegetative filters, and other measures to reduce overland flow;
6) Reclaiming all lands disturbed by mining as contemporaneously as practicable.

In addition to the use of sediment control measures and BMPs within the disturbed mine area, CSMRR require coal mining haulroads to be designed and constructed to ensure environmental protection appropriate for their intended use. In a watershed where pollution load reductions for solids are necessary for active mining operations to meet an approved TMDL, haulroad design, construction, and maintenance shall be performed considerate of the TMDL. This may include, but not limited to:

1) Using non-toxic-forming substances in road surfacing;
2) Paving haulroads;
3) Increasing the size of haulroad sumps.

Reduction in the sedimentation and mineralization of runoff attendant to mined land erosion and strata exposure may be achieved with sediment control measures and BMPs. Operation and reclamation plans mandated by CSMRR can be designed and developed to incorporate a BMP approach for meeting waste load allocations and pollution load reductions included in a TMDL for stream segments and watersheds where benthic stressors have been identified as suspended and dissolved solids. In selecting particular BMPs to meet the TDS reduction requirements VADEQ and/or DMME will develop a cost analysis for these pollutant reductions in accordance with the SWCB directive during the September 27, 2005 meeting. This approach will be implemented in Virginia in lieu of altered effluent limitations for permitted coal mine point source discharges.

12.2 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to ongoing water quality improvement efforts aimed at restoring water quality in Virginia's streams. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of this effort. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy.

12.3 Reasonable Assurance for Implementation

12.3.1 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with Guidance Memo No. 03-2004 (2003), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or when deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not be required during the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s). At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30th of each year.

VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request that the monitoring managers in each regional office increase the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent upon staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that water quality standards are being met in watersheds where corrective actions have been installed (whether or not a TMDL or IP has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (total suspended solids, dissolved oxygen, etc.) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

12.3.2 Follow-up Monitoring – Benthic

VADEQ will continue to monitor biological monitoring stations 6AKOX008.51 in Knox Creek and 6APPW000.60 in Pawpaw Creek, as implementation of corrective actions in the watershed occurs to evaluate when the Stage 1 implementation goals are achieved. Monitoring after corrective actions occur allows the most effective use of monitoring resources in the regional office. VADEQ will use data from these monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the General Standard. Should the benthic community recover prior to attainment of the TDS and TSS WLAs, VADEQ and DMME will propose to EPA and the SWCB that the TDS/TSS WLAs be amended to reflect new information.

12.3.3 Regulatory Framework

While section 303(d) of the CWA and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the SWCB to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process and permitted sources are not usually addressed during the development of a TMDL implementation plan. However, the NPDES permits which cover the municipal separate storm sewer systems (MS4s) are expected to be included in TMDL implementation plans. For the implementation of the TMDL's LA component, a TMDL implementation plan addressing the WQMIRA requirements, at a minimum, will be developed.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADMME, VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the state's Water Quality Management Plans (WQMPs). The WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin. VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the SWCB for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

12.3.4 Stormwater Permits

VADEQ and VADCR coordinate separate State programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with "industrial activities", while VADCR regulates stormwater discharges from construction sites and from MS4s.

EPA approved VADCR's VPDES stormwater program on December 30, 2004. VADCR's regulations became effective on January 29, 2005. VADEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES, MS4, and construction stormwater permitting programs. More information is available on VADCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp.

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is VADCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when: (2) Numeric effluent limitations are infeasible…"

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Office of Water, 2002).

If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacterial TMDLs (see section 11.3.5 below.) At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis (UAA). Any changes to the TMDL resulting from water quality standards change on Knox Creek and Pawpaw Creek would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL implementation plans. An IP will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL IPs since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia's Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm.

12.3.5 Implementation Funding Sources

Funding sources for implementations will be identified by VADCR and DMME and the stakeholders. According to DMME's website, "Over 71,000 acres of land in Virginia have been affected by coal mining. It is estimated that it would take approximately 55 years at the present rate of funding and reclamation construction to reclaim just the high priority Abandoned Mine Land (AML) sites" (DMME, 2005). In addition, it would cost more than $300 million to reclaim the AML sites causing environmental degradation. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Additional funding sources may be available through the U. S. Office of Surface Mining.

12.3.6 Use Attainability Analysis

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevent the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;
3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/pdf/WQS05A_1.pdf.

12.3.7 Addressing Wildlife Contributions

In some cases, water quality modeling indicates that even after removal of all bacteria sources other than wildlife, some streams will not attain standards under all flow regimes at all times. As is the case for Knox Creek, this stream may not be able to attain standards without some reduction in wildlife load. **Virginia and the EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.**

Although previous TMDLs for the Commonwealth have not addressed wildlife reductions in first stage goals, some localities have already introduced wildlife management practices. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the SWCB adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria were approved by the EPA and became effective in February 2004. Additional information can be found at http://www.deq.state.va.us/wqs/rule.html.

Based on the above, the EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the Stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 11.1 above. VADEQ will reassess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

13. PUBLIC PARTICIPATION

The development of the Knox Creek and Pawpaw Creek TMDLs greatly benefited from public involvement. Table 13.1 details the public participation throughout the project. The Technical Advisory Committee (TAC) meeting took place on July 12, 2005 at the Hurley Elementary and Middle School in Hurley, Virginia with 17 people in attendance. The meeting brought together representatives from VADCR, VADEQ, DMME, the Big Sandy Soil and Water Conservation District, coal mining representatives and MapTech, Inc. All agency representatives and county and locality staff were invited to the TAC meeting through a mailed letter or e-mail.

The first public meeting was held at the Hurley Elementary and Middle School in Hurley, Virginia on July 12, 2005; 22 people attended, including 15 landowners, 2 consultants, and 5 agency representatives. The meeting was publicized by placing notices in the Virginia Register, the community section of the Mountaineer newspaper, mailing notices to watershed landowners, all agencies, Buchanan County and Hurley locality staff and placing ten signs on the road right-of-way along Knox and Pawpaw Creeks.

The final public meeting was held at the Hurley Elementary and Middle School Cafeteria in Hurley, Virginia on February 6, 2006. 34 people attended, including 23 watershed citizens, nine agency representatives, and two consultants. The meeting was publicized with notices in the *Virginia Register* and the *Mountaineer* and on the VADEQ website. In addition, 139 mailings went out to watershed landowners, agencies, Buchanan County and Hurley locality staff, and the Kentucky DEP. Finally, ten signs were placed on the road right-of-way along the Knox and Pawpaw Creeks. There was 30-day public comment period. Comments were received in the form of three letters and one outline of questions, comments, and changes requested by the Virginia Coalfields TMDL Group. VADEQ sent responses to these comments and appropriate changes were made to the draft document.

Table 13.1 Public participation during TMDL development for the Knox Creek and Pawpaw Creek watersheds.

Date	Location	Attendance[1]	Type	Format
7/12/205	Hurley Elementary and Middle Schools Hurley, VA	17	TAC meeting	Publicized to government agencies
7/12/205	Hurley Elementary and Middle Schools Hurley, VA	22	1st public	Open to public at large
2/6/06	Hurley Elementary and Middle Schools Hurley, VA	34	Final public	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of a stakeholders' committee as well as open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the express purpose of formulating the TMDL Implementation Plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from DMME, VADEQ, VADCR, and local governments. This committee will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity*. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. **(2)**

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). [2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* ***Respiration.***

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

Metric ton (Mg or t). A unit of mass equivalent to 1,000 kilograms. An annual load of a pollutant is typically reported in metric tons per year (t/yr).

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (*e.g.*, pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Re-mining. Extracting resources from land previously mined. This method is often used to reclaim abandoned mine areas.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff*. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area*. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water*. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards*. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Ton (T). A unit of measure of mass equivalent to 2,200 English lbs.

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under* *investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

DMLR. Virginia Department of mine Land Reclamation.

DMME. Virginia Department of Mines, Minerals, and Energy.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment**.** *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality**.** *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit**.** *A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria**.** *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are* *necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

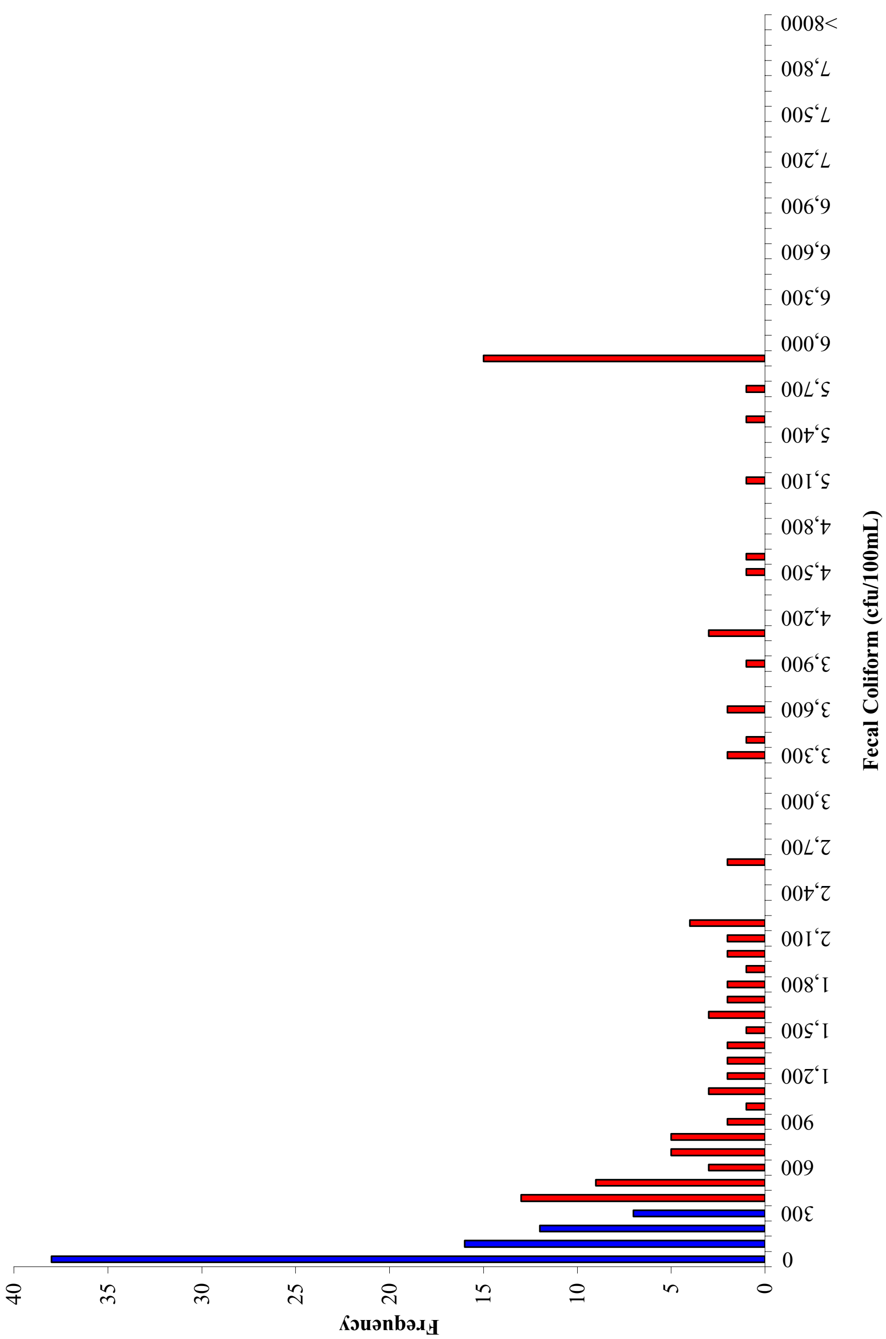

Figure A.1 Frequency analysis of fecal coliform concentrations at station 6AKOX006.52 in the Knox Creek impairment for the period form February 1980 to June 2004.

*Red indicates a value which violates the listing standard of 400 cfu.100 mL.

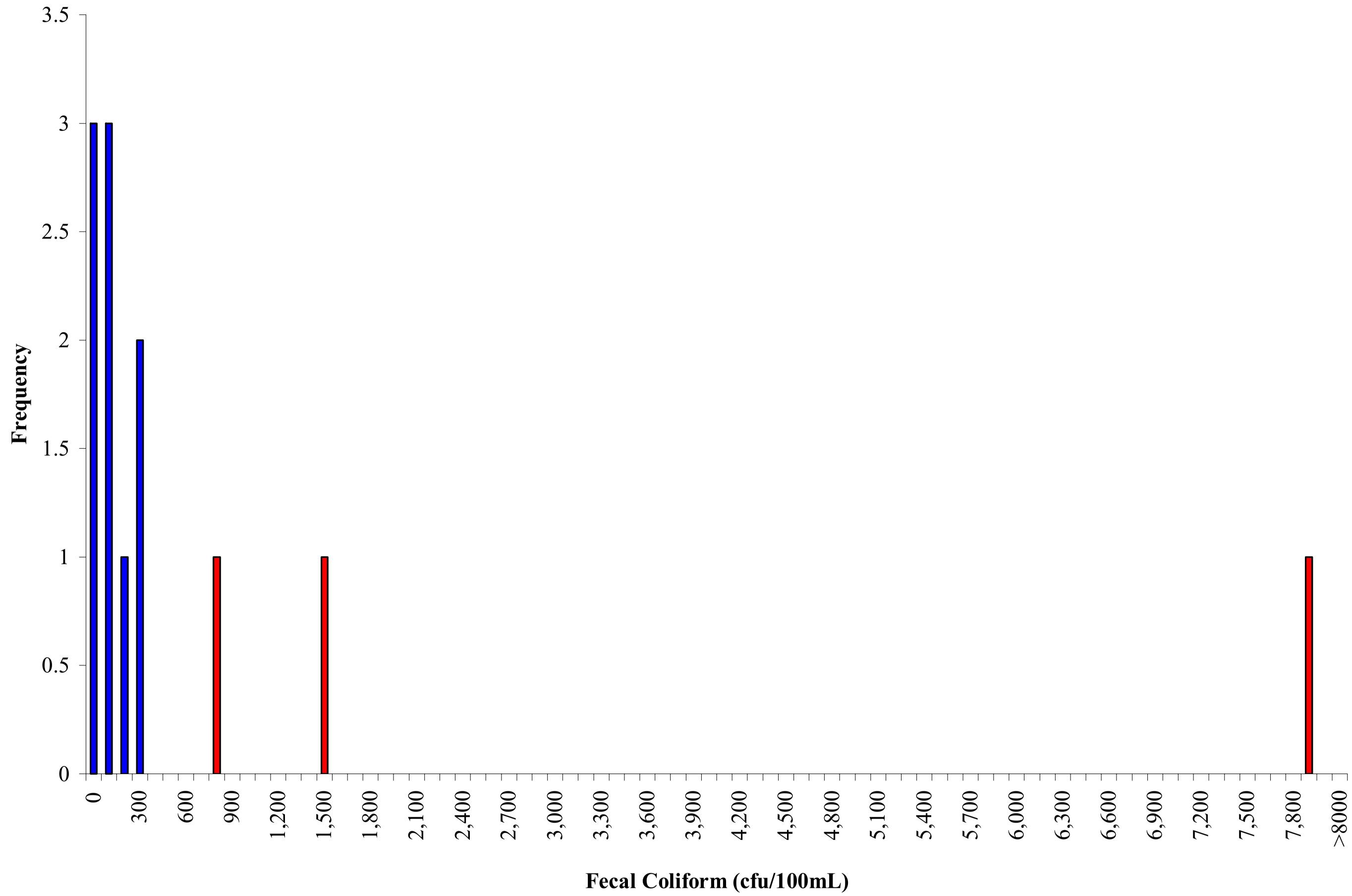

Figure A.2 Frequency analysis of fecal coliform concentrations at station 6AKOX014.17 in the Knox Creek impairment for the period form July 2001 to June 2003.

*Red indicates a value which violates the listing standard of 400 cfu.100 mL.

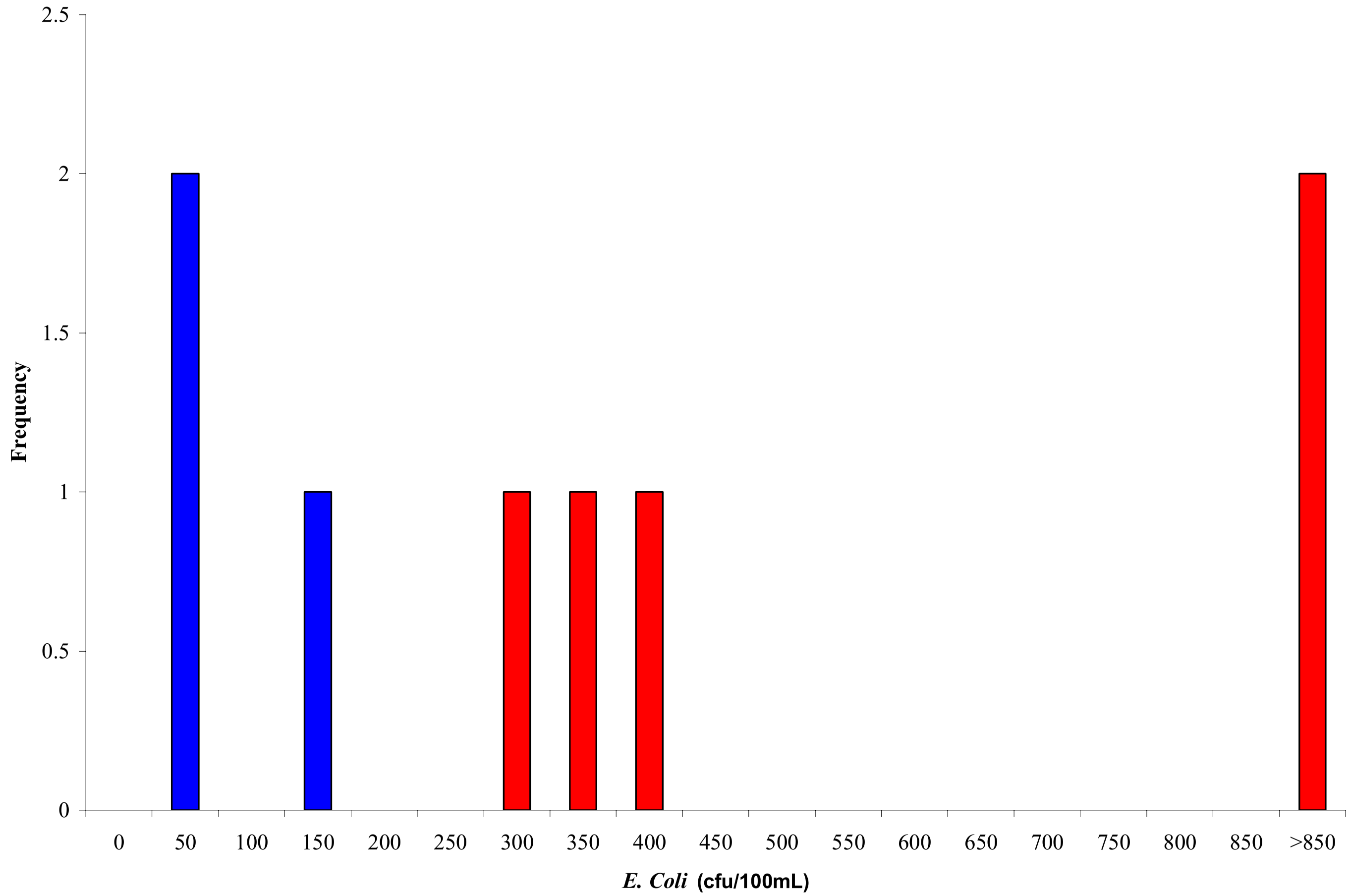

Figure A.3 Frequency analysis of E. coli concentrations at station 6AKOX006.52 in the Knox Creek impairment for the period November 2003 to June 2004.

* Red indicates a value which violates the listing standard of 235 cfu/100mL.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions of land applied fecal coliform load by land use for the Virginia portion of the Knox Creek watershed (subwatersheds 1-24).

Land use	Active	AML	Cropland	Forest	LAX	Pasture	Reclaimed	Residential	Salted Roads
January	6.68E+11	8.26E+11	9.41E+11	3.41E+13	2.29E+11	9.89E+12	2.90E+11	9.67E+13	7.48E+11
February	6.03E+11	7.46E+11	8.50E+11	3.08E+13	2.07E+11	8.93E+12	2.62E+11	8.73E+13	6.75E+11
March	6.60E+11	8.16E+11	9.30E+11	3.37E+13	2.82E+11	9.82E+12	2.86E+11	9.67E+13	7.39E+11
April	6.29E+11	7.78E+11	8.86E+11	3.21E+13	3.38E+11	9.42E+12	2.73E+11	9.35E+13	7.04E+11
May	6.50E+11	8.04E+11	9.16E+11	3.32E+13	3.49E+11	9.74E+12	2.82E+11	9.67E+13	7.28E+11
June	6.21E+11	7.69E+11	8.76E+11	3.17E+13	3.89E+11	9.36E+12	2.69E+11	9.35E+13	6.96E+11
July	6.42E+11	7.94E+11	9.05E+11	3.28E+13	4.02E+11	9.67E+12	2.78E+11	9.67E+13	7.19E+11
August	6.42E+11	7.94E+11	9.05E+11	3.28E+13	4.02E+11	9.67E+12	2.78E+11	9.67E+13	7.19E+11
September	6.29E+11	7.78E+11	8.86E+11	3.21E+13	3.38E+11	9.42E+12	2.73E+11	9.35E+13	7.04E+11
October	6.60E+11	8.16E+11	9.30E+11	3.37E+13	2.82E+11	9.82E+12	2.86E+11	9.67E+13	7.39E+11
November	6.39E+11	7.90E+11	9.00E+11	3.26E+13	2.73E+11	9.51E+12	2.77E+11	9.36E+13	7.15E+11
December	6.68E+11	8.26E+11	9.41E+11	3.41E+13	2.29E+11	9.89E+12	2.90E+11	9.67E+13	7.48E+11
Total	**7.71E+12**	**9.54E+12**	**1.09E+13**	**3.94E+14**	**3.72E+12**	**1.15E+14**	**3.34E+12**	**1.14E+15**	**8.63E+12**

Table B.2 Current conditions of land applied fecal coliform load by land use for the Kentucky portion of the Knox Creek watershed (subwatersheds 17,20,24).

Land use	KY Active	KY AML	KY Cropland	KY Forest	KY Pasture	KY Reclaimed	KY Salted Roads	KY Water
January	1.17E+11	1.14E+10	1.10E+08	3.10E+12	2.10E+09	2.55E+10	2.39E+08	3.04E+11
February	1.05E+11	1.03E+10	9.96E+07	2.80E+12	1.90E+09	2.30E+10	2.16E+08	2.74E+11
March	1.17E+11	1.14E+10	1.10E+08	3.08E+12	2.10E+09	2.54E+10	2.36E+08	3.64E+11
April	1.13E+11	1.10E+10	1.07E+08	2.96E+12	2.03E+09	2.44E+10	2.26E+08	4.27E+11
May	1.16E+11	1.14E+10	1.10E+08	3.06E+12	2.10E+09	2.52E+10	2.33E+08	4.41E+11
June	1.13E+11	1.10E+10	1.07E+08	2.94E+12	2.03E+09	2.43E+10	2.23E+08	4.85E+11
July	1.16E+11	1.14E+10	1.10E+08	3.04E+12	2.10E+09	2.51E+10	2.31E+08	5.01E+11
August	1.16E+11	1.14E+10	1.10E+08	3.04E+12	2.10E+09	2.51E+10	2.31E+08	5.01E+11
September	1.13E+11	1.10E+10	1.07E+08	2.96E+12	2.03E+09	2.44E+10	2.26E+08	4.27E+11
October	1.17E+11	1.14E+10	1.10E+08	3.08E+12	2.10E+09	2.54E+10	2.36E+08	3.64E+11
November	1.13E+11	1.10E+10	1.07E+08	2.98E+12	2.03E+09	2.46E+10	2.29E+08	3.52E+11
December	1.17E+11	1.14E+10	1.10E+08	3.10E+12	2.10E+09	2.55E+10	2.39E+08	3.04E+11
Total	**1.37E+12**	**1.34E+11**	**1.30E+09**	**3.61E+13**	**2.47E+10**	**2.98E+11**	**2.76E+09**	**4.74E+12**

Table B.3 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Knox Creek watershed (subwatersheds 1-24).

Source Type	Reach ID	January	February	March	April	May	June
Human/Pet	1	5.88E+10	5.31E+10	5.88E+10	5.69E+10	5.88E+10	5.69E+10
Livestock	1	6.03E+08	5.44E+08	8.04E+08	1.17E+09	1.21E+09	1.36E+09
Wildlife	1	6.86E+10	6.20E+10	9.87E+10	1.33E+11	1.37E+11	1.62E+11
Human/Pet	2	7.21E+10	6.51E+10	7.21E+10	6.98E+10	7.21E+10	6.98E+10
Livestock	2	8.35E+08	7.54E+08	1.11E+09	1.62E+09	1.67E+09	1.89E+09
Wildlife	2	5.95E+10	5.38E+10	8.57E+10	1.15E+11	1.19E+11	1.40E+11
Human/Pet	3	7.59E+10	6.85E+10	7.59E+10	7.34E+10	7.59E+10	7.34E+10
Livestock	3	1.75E+09	1.58E+09	2.34E+09	3.39E+09	3.50E+09	3.96E+09
Wildlife	3	3.61E+10	3.26E+10	5.20E+10	6.99E+10	7.22E+10	8.52E+10
Human/Pet	4	1.57E+11	1.42E+11	1.57E+11	1.52E+11	1.57E+11	1.52E+11
Livestock	4	1.09E+09	9.88E+08	1.46E+09	2.12E+09	2.19E+09	2.47E+09
Wildlife	4	6.02E+10	5.43E+10	8.66E+10	1.16E+11	1.20E+11	1.42E+11
Human/Pet	5	3.98E+10	3.59E+10	3.98E+10	3.85E+10	3.98E+10	3.85E+10
Livestock	5	6.78E+08	6.12E+08	9.04E+08	1.31E+09	1.36E+09	1.53E+09
Wildlife	5	2.99E+10	2.70E+10	4.31E+10	5.79E+10	5.98E+10	7.06E+10
Human/Pet	6	1.78E+10	1.61E+10	1.78E+10	1.72E+10	1.78E+10	1.72E+10
Livestock	6	1.69E+07	1.53E+07	2.26E+07	3.28E+07	3.39E+07	3.83E+07
Wildlife	6	3.56E+10	3.21E+10	5.12E+10	6.88E+10	7.11E+10	8.39E+10
Human/Pet	7	1.22E+10	1.10E+10	1.22E+10	1.18E+10	1.22E+10	1.18E+10
Livestock	7	1.36E+08	1.22E+08	1.81E+08	2.62E+08	2.71E+08	3.06E+08
KY-Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KY-Wildlife	7	1.02E+08	9.21E+07	1.15E+08	1.28E+08	1.32E+08	1.41E+08
Wildlife	7	4.35E+10	3.93E+10	6.26E+10	8.41E+10	8.69E+10	1.03E+11
Human/Pet	8	4.97E+10	4.49E+10	4.97E+10	4.81E+10	4.97E+10	4.81E+10
Livestock	8	1.53E+09	1.38E+09	2.04E+09	2.96E+09	3.06E+09	3.45E+09
Wildlife	8	3.20E+10	2.89E+10	4.61E+10	6.20E+10	6.40E+10	7.56E+10
Human/Pet	9	6.40E+10	5.78E+10	6.40E+10	6.19E+10	6.40E+10	6.19E+10
Livestock	9	1.02E+09	9.18E+08	1.36E+09	1.97E+09	2.03E+09	2.30E+09
Wildlife	9	3.43E+10	3.10E+10	4.93E+10	6.63E+10	6.85E+10	8.08E+10
Human/Pet	10	8.51E+10	7.68E+10	8.51E+10	8.23E+10	8.51E+10	8.23E+10
Livestock	10	9.49E+08	8.57E+08	1.27E+09	1.84E+09	1.90E+09	2.14E+09
Wildlife	10	4.08E+10	3.68E+10	5.87E+10	7.89E+10	8.15E+10	9.62E+10
Human/Pet	11	2.17E+10	1.96E+10	2.17E+10	2.10E+10	2.17E+10	2.10E+10
Livestock	11	4.91E+08	4.44E+08	6.55E+08	9.51E+08	9.83E+08	1.11E+09
Wildlife	11	1.29E+10	1.16E+10	1.85E+10	2.49E+10	2.57E+10	3.03E+10
Human/Pet	12	3.54E+10	3.20E+10	3.54E+10	3.43E+10	3.54E+10	3.43E+10
Livestock	12	3.65E+08	3.30E+08	4.87E+08	7.07E+08	7.31E+08	8.25E+08
Wildlife	12	1.95E+10	1.76E+10	2.80E+10	3.77E+10	3.89E+10	4.60E+10
Human/Pet	13	4.05E+10	3.66E+10	4.05E+10	3.92E+10	4.05E+10	3.92E+10
Livestock	13	5.15E+08	4.66E+08	6.87E+08	9.98E+08	1.03E+09	1.16E+09
Wildlife	13	4.22E+10	3.82E+10	6.08E+10	8.17E+10	8.44E+10	9.96E+10
Human/Pet	14	5.63E+10	5.08E+10	5.63E+10	5.45E+10	5.63E+10	5.45E+10
Livestock	14	2.54E+08	2.30E+08	3.39E+08	4.92E+08	5.08E+08	5.74E+08
Wildlife	14	4.78E+10	4.32E+10	6.88E+10	9.25E+10	9.56E+10	1.13E+11

Table B.3 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Knox Creek watershed (subwatersheds 1-24)(cont).

Source Type	Reach ID	January	February	March	April	May	June
Human/Pet	15	2.81E+10	2.54E+10	2.81E+10	2.72E+10	2.81E+10	2.72E+10
Livestock	15	1.53E+08	1.38E+08	2.03E+08	2.95E+08	3.05E+08	3.44E+08
Wildlife	15	2.62E+10	2.36E+10	3.77E+10	5.06E+10	5.23E+10	6.17E+10
Human/Pet	16	2.58E+10	2.33E+10	2.58E+10	2.49E+10	2.58E+10	2.49E+10
Livestock	16	3.90E+08	3.52E+08	5.19E+08	7.54E+08	7.79E+08	8.80E+08
Wildlife	16	2.28E+10	2.06E+10	3.28E+10	4.41E+10	4.56E+10	5.38E+10
Human/Pet	17	2.76E+11	2.49E+11	2.76E+11	2.67E+11	2.76E+11	2.67E+11
Livestock	17	1.68E+09	1.51E+09	2.24E+09	3.25E+09	3.35E+09	3.79E+09
Wildlife	17	1.65E+11	1.49E+11	2.37E+11	3.19E+11	3.30E+11	3.89E+11
Human/Pet	18	9.62E+09	8.69E+09	9.62E+09	9.31E+09	9.62E+09	9.31E+09
Livestock	18	6.78E+07	6.12E+07	9.04E+07	1.31E+08	1.36E+08	1.53E+08
Wildlife	18	3.43E+10	3.10E+10	4.94E+10	6.64E+10	6.86E+10	8.10E+10
Human/Pet	19	4.60E+10	4.15E+10	4.60E+10	4.45E+10	4.60E+10	4.45E+10
Livestock	19	4.23E+08	3.82E+08	5.65E+08	8.20E+08	8.47E+08	9.56E+08
Wildlife	19	5.39E+10	4.87E+10	7.75E+10	1.04E+11	1.08E+11	1.27E+11
Human/Pet	20	6.14E+10	5.54E+10	6.14E+10	5.94E+10	6.14E+10	5.94E+10
Livestock	20	3.56E+08	3.21E+08	4.74E+08	6.88E+08	7.11E+08	8.03E+08
KY-Human/Pet	20	8.37E+10	7.56E+10	8.37E+10	8.10E+10	8.37E+10	8.10E+10
KY-Wildlife	20	4.45E+10	4.02E+10	6.24E+10	8.24E+10	8.52E+10	9.97E+10
Wildlife	20	3.48E+10	3.15E+10	5.01E+10	6.73E+10	6.96E+10	8.21E+10
Human/Pet	21	2.83E+10	2.56E+10	2.83E+10	2.74E+10	2.83E+10	2.74E+10
Livestock	21	4.57E+08	4.13E+08	6.10E+08	8.85E+08	9.15E+08	1.03E+09
Wildlife	21	2.58E+10	2.33E+10	3.71E+10	4.99E+10	5.15E+10	6.08E+10
Human/Pet	22	7.34E+10	6.63E+10	7.34E+10	7.11E+10	7.34E+10	7.11E+10
Livestock	22	5.42E+08	4.90E+08	7.23E+08	1.05E+09	1.08E+09	1.22E+09
Wildlife	22	8.63E+10	7.80E+10	1.24E+11	1.67E+11	1.73E+11	2.04E+11
Human/Pet	23	3.29E+10	2.97E+10	3.29E+10	3.18E+10	3.29E+10	3.18E+10
Livestock	23	1.86E+08	1.68E+08	2.49E+08	3.61E+08	3.73E+08	4.21E+08
Wildlife	23	3.50E+10	3.16E+10	5.04E+10	6.77E+10	7.00E+10	8.26E+10
Human/Pet	24	1.53E+10	1.39E+10	1.53E+10	1.49E+10	1.53E+10	1.49E+10
Livestock	24	1.02E+08	9.18E+07	1.36E+08	1.97E+08	2.03E+08	2.30E+08
KY-Human/Pet	24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KY-Wildlife	24	8.59E+08	7.75E+08	1.15E+09	1.47E+09	1.51E+09	1.74E+09
Total		**2.57E+12**	**2.32E+12**	**3.06E+12**	**3.56E+12**	**3.68E+12**	**4.02E+12**

Table B.3 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Knox Creek watershed (subwatersheds 1-24)(cont).

Source Type	Reach ID	July	August	September	October	November	December
Human/Pet	1	5.88E+10	5.88E+10	5.69E+10	5.88E+10	5.69E+10	5.88E+10
Livestock	1	1.41E+09	1.41E+09	1.17E+09	8.04E+08	7.78E+08	6.03E+08
Wildlife	1	1.67E+11	1.67E+11	1.33E+11	9.87E+10	9.55E+10	6.86E+10
Human/Pet	2	7.21E+10	7.21E+10	6.98E+10	7.21E+10	6.98E+10	7.21E+10
Livestock	2	1.95E+09	1.95E+09	1.62E+09	1.11E+09	1.08E+09	8.35E+08
Wildlife	2	1.45E+11	1.45E+11	1.15E+11	8.57E+10	8.29E+10	5.95E+10
Human/Pet	3	7.59E+10	7.59E+10	7.34E+10	7.59E+10	7.34E+10	7.59E+10
Livestock	3	4.09E+09	4.09E+09	3.39E+09	2.34E+09	2.26E+09	1.75E+09
Wildlife	3	8.80E+10	8.80E+10	6.99E+10	5.20E+10	5.03E+10	3.61E+10
Human/Pet	4	1.57E+11	1.57E+11	1.52E+11	1.57E+11	1.52E+11	1.57E+11
Livestock	4	2.55E+09	2.55E+09	2.12E+09	1.46E+09	1.41E+09	1.09E+09
Wildlife	4	1.47E+11	1.47E+11	1.16E+11	8.66E+10	8.38E+10	6.02E+10
Human/Pet	5	3.98E+10	3.98E+10	3.85E+10	3.98E+10	3.85E+10	3.98E+10
Livestock	5	1.58E+09	1.58E+09	1.31E+09	9.04E+08	8.74E+08	6.78E+08
Wildlife	5	7.30E+10	7.30E+10	5.79E+10	4.31E+10	4.17E+10	2.99E+10
Human/Pet	6	1.78E+10	1.78E+10	1.72E+10	1.78E+10	1.72E+10	1.78E+10
Livestock	6	3.95E+07	3.95E+07	3.28E+07	2.26E+07	2.19E+07	1.69E+07
Wildlife	6	8.67E+10	8.67E+10	6.88E+10	5.12E+10	4.95E+10	3.56E+10
Human/Pet	7	1.22E+10	1.22E+10	1.18E+10	1.22E+10	1.18E+10	1.22E+10
Livestock	7	3.16E+08	3.16E+08	2.62E+08	1.81E+08	1.75E+08	1.36E+08
KY-Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KY-Wildlife	7	1.46E+08	1.46E+08	1.28E+08	1.15E+08	1.12E+08	1.02E+08
Wildlife	7	1.06E+11	1.06E+11	8.41E+10	6.26E+10	6.06E+10	4.35E+10
Human/Pet	8	4.97E+10	4.97E+10	4.81E+10	4.97E+10	4.81E+10	4.97E+10
Livestock	8	3.57E+09	3.57E+09	2.96E+09	2.04E+09	1.97E+09	1.53E+09
Wildlife	8	7.81E+10	7.81E+10	6.20E+10	4.61E+10	4.46E+10	3.20E+10
Human/Pet	9	6.40E+10	6.40E+10	6.19E+10	6.40E+10	6.19E+10	6.40E+10
Livestock	9	2.37E+09	2.37E+09	1.97E+09	1.36E+09	1.31E+09	1.02E+09
Wildlife	9	8.35E+10	8.35E+10	6.63E+10	4.93E+10	4.77E+10	3.43E+10
Human/Pet	10	8.51E+10	8.51E+10	8.23E+10	8.51E+10	8.23E+10	8.51E+10
Livestock	10	2.21E+09	2.21E+09	1.84E+09	1.27E+09	1.22E+09	9.49E+08
Wildlife	10	9.94E+10	9.94E+10	7.89E+10	5.87E+10	5.68E+10	4.08E+10
Human/Pet	11	2.17E+10	2.17E+10	2.10E+10	2.17E+10	2.10E+10	2.17E+10
Livestock	11	1.15E+09	1.15E+09	9.51E+08	6.55E+08	6.34E+08	4.91E+08
Wildlife	11	3.14E+10	3.14E+10	2.49E+10	1.85E+10	1.79E+10	1.29E+10
Human/Pet	12	3.54E+10	3.54E+10	3.43E+10	3.54E+10	3.43E+10	3.54E+10
Livestock	12	8.53E+08	8.53E+08	7.07E+08	4.87E+08	4.72E+08	3.65E+08
Wildlife	12	4.75E+10	4.75E+10	3.77E+10	2.80E+10	2.71E+10	1.95E+10
Human/Pet	13	4.05E+10	4.05E+10	3.92E+10	4.05E+10	3.92E+10	4.05E+10
Livestock	13	1.20E+09	1.20E+09	9.98E+08	6.87E+08	6.65E+08	5.15E+08
Wildlife	13	1.03E+11	1.03E+11	8.17E+10	6.08E+10	5.88E+10	4.22E+10
Human/Pet	14	5.63E+10	5.63E+10	5.45E+10	5.63E+10	5.45E+10	5.63E+10
Livestock	14	5.93E+08	5.93E+08	4.92E+08	3.39E+08	3.28E+08	2.54E+08
Wildlife	14	1.17E+11	1.17E+11	9.25E+10	6.88E+10	6.66E+10	4.78E+10
Human/Pet	15	2.81E+10	2.81E+10	2.72E+10	2.81E+10	2.72E+10	2.81E+10
Livestock	15	3.56E+08	3.56E+08	2.95E+08	2.03E+08	1.97E+08	1.53E+08
Wildlife	15	6.38E+10	6.38E+10	5.06E+10	3.77E+10	3.64E+10	2.62E+10

Table B.3 Monthly, directly deposited fecal coliform loads (cfu/day) in each reach of the Knox Creek watershed (subwatersheds 1-24)(cont).

Source Type	Reach ID	July	August	September	October	November	December
Human/Pet	16	2.58E+10	2.58E+10	2.49E+10	2.58E+10	2.49E+10	2.58E+10
Livestock	16	9.09E+08	9.09E+08	7.54E+08	5.19E+08	5.03E+08	3.90E+08
Wildlife	16	5.56E+10	5.56E+10	4.41E+10	3.28E+10	3.18E+10	2.28E+10
Human/Pet	17	2.76E+11	2.76E+11	2.67E+11	2.76E+11	2.67E+11	2.76E+11
Livestock	17	3.91E+09	3.91E+09	3.25E+09	2.24E+09	2.16E+09	1.68E+09
Wildlife	17	4.02E+11	4.02E+11	3.19E+11	2.37E+11	2.30E+11	1.65E+11
Human/Pet	18	9.62E+09	9.62E+09	9.31E+09	9.62E+09	9.31E+09	9.62E+09
Livestock	18	1.58E+08	1.58E+08	1.31E+08	9.04E+07	8.75E+07	6.78E+07
Wildlife	18	8.37E+10	8.37E+10	6.64E+10	4.94E+10	4.78E+10	3.43E+10
Human/Pet	19	4.60E+10	4.60E+10	4.45E+10	4.60E+10	4.45E+10	4.60E+10
Livestock	19	9.88E+08	9.88E+08	8.20E+08	5.65E+08	5.46E+08	4.23E+08
Wildlife	19	1.31E+11	1.31E+11	1.04E+11	7.75E+10	7.50E+10	5.39E+10
Human/Pet	20	6.14E+10	6.14E+10	5.94E+10	6.14E+10	5.94E+10	6.14E+10
Livestock	20	8.30E+08	8.30E+08	6.88E+08	4.74E+08	4.59E+08	3.56E+08
KY-Human/Pet	20	8.37E+10	8.37E+10	8.10E+10	8.37E+10	8.10E+10	8.37E+10
KY-Wildlife	20	1.03E+11	1.03E+11	8.24E+10	6.24E+10	6.04E+10	4.45E+10
Wildlife	20	8.48E+10	8.48E+10	6.73E+10	5.01E+10	4.85E+10	3.48E+10
Human/Pet	21	2.83E+10	2.83E+10	2.74E+10	2.83E+10	2.74E+10	2.83E+10
Livestock	21	1.07E+09	1.07E+09	8.85E+08	6.10E+08	5.90E+08	4.57E+08
Wildlife	21	6.28E+10	6.28E+10	4.99E+10	3.71E+10	3.59E+10	2.58E+10
Human/Pet	22	7.34E+10	7.34E+10	7.11E+10	7.34E+10	7.11E+10	7.34E+10
Livestock	22	1.26E+09	1.26E+09	1.05E+09	7.23E+08	6.99E+08	5.42E+08
Wildlife	22	2.10E+11	2.10E+11	1.67E+11	1.24E+11	1.20E+11	8.63E+10
Human/Pet	23	3.29E+10	3.29E+10	3.18E+10	3.29E+10	3.18E+10	3.29E+10
Livestock	23	4.35E+08	4.35E+08	3.61E+08	2.49E+08	2.41E+08	1.86E+08
Wildlife	23	8.53E+10	8.53E+10	6.77E+10	5.04E+10	4.87E+10	3.50E+10
Human/Pet	24	1.53E+10	1.53E+10	1.49E+10	1.53E+10	1.49E+10	1.53E+10
Livestock	24	2.37E+08	2.37E+08	1.97E+08	1.36E+08	1.31E+08	1.02E+08
KY-Human/Pet	24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KY-Wildlife	24	1.80E+09	1.80E+09	1.47E+09	1.15E+09	1.11E+09	8.59E+08
Total		**4.16E+12**	**4.16E+12**	**3.56E+12**	**3.06E+12**	**2.96E+12**	**2.57E+12**

Table B.4 Existing annual loads from land-based sources for the Virginia portion of the Knox Creek watershed (subwatersheds 1-24).

Source	Active (cfu/day)	AML (cfu/day)	Cropland (cfu/day)	Forest (cfu/day)	LAX (cfu/day)	Pasture (cfu/day)	Reclaimed (cfu/day)	Residential (cfu/day)	Salted_Roads (cfu/day)	Water (cfu/day)
Virginia:										
Human										
Failing Septic Systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.35E+14	0.00E+00	0.00E+00
Straight pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+13
Pet										
Cat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.34E+07	0.00E+00	0.00E+00
Dog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.97E+13	0.00E+00	0.00E+00
Roosters	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E+13	0.00E+00	0.00E+00
Livestock										
Beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E+12	3.95E+13	0.00E+00	0.00E+00	0.00E+00	2.08E+11
Dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.33E+11	9.18E+12	0.00E+00	0.00E+00	0.00E+00	4.85E+10
Hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.31E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.08E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.14E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife										
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E+10
Deer	0.00E+00	5.98E+11	1.57E+11	1.50E+13	5.53E+09	4.96E+10	1.27E+11	4.82E+09	0.00E+00	0.00E+00
Duck	4.10E+07	4.50E+06	7.54E+07	1.46E+09	9.49E+06	2.12E+07	1.32E+07	2.01E+07	5.70E+07	0.00E+00
Muskrat	3.91E+12	4.29E+11	7.19E+12	1.39E+14	9.05E+11	2.02E+12	1.26E+12	1.92E+12	5.44E+12	0.00E+00
Raccoon	3.64E+12	4.75E+12	3.13E+12	1.71E+14	1.37E+11	1.01E+12	1.47E+12	5.43E+11	1.45E+12	0.00E+00
Turkey	0.00E+00	1.86E+09	0.00E+00	4.67E+10	0.00E+00	0.00E+00	3.94E+08	0.00E+00	0.00E+00	0.00E+00
Wildlife	7.55E+12	5.78E+12	1.05E+13	3.25E+14	1.05E+12	3.08E+12	2.86E+12	2.47E+12	6.89E+12	1.53E+10
VA Total	**7.55E+12**	**5.78E+12**	**1.05E+13**	**3.25E+14**	**3.34E+12**	**1.03E+14**	**2.86E+12**	**8.09E+14**	**6.89E+12**	**1.43E+13**

Table B.5 Existing annual loads from land-based sources for the Kentucky portion of the Knox Creek watershed (subwatersheds 7,20,24).

Source	KY Active (cfu/day)	KY AML (cfu/day)	KY Cropland (cfu/day)	KY Forest (cfu/day)	KY Pasture (cfu/day)	KY Reclaimed (cfu/day)	KY Salted Roads (cfu/day)	KY Water (cfu/day)
Kentucky:								
Human								
Failing Septic Systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pet								
Cat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife								
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Deer	0.00E+00	1.60E+10	1.56E+08	1.49E+12	2.97E+09	1.28E+10	0.00E+00	0.00E+00
Duck	8.28E+05	1.53E+03	0.00E+00	1.62E+08	0.00E+00	1.30E+06	2.44E+04	1.60E+07
Muskrat	8.26E+10	1.53E+08	0.00E+00	1.61E+13	0.00E+00	1.30E+11	2.43E+09	1.59E+12
Raccoon	1.29E+12	1.18E+11	1.14E+09	1.85E+13	2.18E+10	1.55E+11	3.29E+08	2.42E+11
Turkey	0.00E+00	4.97E+07	1.21E+05	4.62E+09	2.30E+06	3.97E+07	0.00E+00	0.00E+00
KY Total	**1.37E+12**	**1.34E+11**	**1.30E+09**	**3.61E+13**	**2.48E+10**	**2.98E+11**	**2.76E+09**	**1.83E+12**

APPENDIX C

TMDLs FOR FUTURE CONDITIONS

Table C.1 Average annual *E. coli* loads (cfu/year) modeled for the Knox Creek watershed impairment after TMDL allocation with permitted point source loads increased five times.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Knox Creek	2.35E+11	1.24E+13	Implicit	1.26E+13
VA0026972	*6.97E+10*			
VA0067521	*1.48E+11*			
VAG400180	*4.36E+09*			
VAG400391	*4.36E+09*			
VAG400502	*4.36E+09*			